Animal Feeding Operations Technical Workgroup Report

On:

Air Emissions Characterization,
Dispersion Modeling, and
Best Management Practices

Prepared by:

The Iowa Department of Natural Resources
Animal Feeding Operations Technical Workgroup

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1.0 Introduction

In recent years, livestock production in Iowa has undergone a dramatic shift, as fewer farms produce greater numbers of animals at each farm. As the number of animals at a given farm has increased, so have the air emissions from these farms. Some of the rural neighbors of these animal feeding operations (AFOs) have expressed concern that the increasing amount of air contaminants present at their homes and on their property is decreasing their quality of life. To increase the understanding and awareness of this issue, the Iowa Department of Natural Resources (DNR) Animal Feeding Operations Technical Workgroup was convened on February 5th, 2004, with the following mission:

"To determine air emissions characterization tools and techniques, ambient air modeling methodologies, and best management practices that can be used to estimate and mitigate air quality impacts that may occur as a result of air emissions from animal feeding operations, and to provide this information to the public."

For the workgroup, the DNR solicited participation from organizations with working knowledge of agricultural practices and technical expertise, including agricultural commodity groups, industrial associations, environmental organizations, academia, and government agencies. Workgroup participant organizations included:

- Iowa Air Emissions Assistance Program
- Iowa Chapter of Sierra Club
- Iowa Citizens for Community Improvement
- Iowa Department of Economic Development
- Iowa Department of Natural Resources
- Iowa Department of Public Health
- Iowa State Association of Counties
- Iowa State University
- Izaac Walton League
- National Soil Tilth Laboratory
- The University of Iowa
- U.S. Environmental Protection Agency

A list of all individual contributors to the workgroup is located in Table 1-1.

1.1 Purpose

Currently, there are a number of technologies and methods available that have been designed to reduce odor and gas emissions from AFOs, and these are commonly referred to as “best management practices.” Although best management practices themselves are extremely useful in mitigating emissions of air contaminants, it is sometimes unclear if the practices will sufficiently reduce concentrations at a nearby residence. One tool that is available to predict whether or not a best management practice will be effective at various distances away from the livestock facility is dispersion modeling. Dispersion models are routinely used to estimate the concentration of pollutants emitted into the atmosphere. However, the ability of the model to accurately estimate downwind pollutant concentrations remains highly dependent on an accurate estimate of pollutant emission rates from each source. Therefore, it is necessary to have what are called “emission factors”, which are an estimate of the rate at which a pollutant is released from a source Emission factors are determined scientifically through research using instruments that can monitor the speed of a pollutants release. This workgroup provided an opportunity for the DNR to gain valuable insight and expertise from individuals with technical knowledge in these areas has part of a continuing effort to develop a working understanding of the complex technical issues involved in air quality issues associated with AFOs.

To complete the mission of the workgroup it was necessary to subdivide the workgroup into three smaller workgroups focusing on the areas of air emissions characterization, ambient air modeling, and best management practices. This report contains a compilation of the findings and recommendations of the three workgroups.

1.2 Process
The initial workgroup meeting was held on February 5th, 2004. Each of the three smaller workgroups consisted of seven to ten individuals, including a group facilitator and technical support staff from the DNR. A list of issues developed by DNR was presented to each workgroup that outlined specific topics that each workgroup was to consider. The workgroups were given the option to further refine the list as the process moved forward. The workgroups met periodically from February through August, 2004. A joint meeting of the workgroups was held on August 11, 2004 to allow the individual workgroups to update each other on their progress and activities. On November 1, 2004, another joint meeting of the workgroups was held to present and discuss comments on a draft of this report. These comments were incorporated as appropriate into a revised draft workgroup report that was issued for workgroup review and comment on November 24, 2004. Comments received on the revised draft workgroup report were reviewed by the workgroup facilitators and technical support staff and incorporated as appropriate into this final report.

1.3 Report Organization
This report summarizes the processes, assumptions, data, and recommendations of each of the three workgroups. Chapter 2 summarizes the findings and recommendations of the Best Management Practices workgroup. Chapters 3 and 4 summarize the findings and recommendations of the Air Emissions Characterization and Dispersion Modeling workgroups, respectively.

Table 1-1

Contributors to the Iowa Department of Natural Resources
Animal Feeding Operations Technical Workgroup

Name	Organization	Workgroup
Banwart, Alan	U.S. EPA Region 7	All
Barton, Charles	Iowa Department of Public Health	Air Emissions
Berhns, Sue	Iowa Air Emissions Assistance Program	BMP
Bundy, Dwaine	Iowa State University	Dispersion Modeling
Bunton, Bryan	Iowa Department of Natural Resources	Dispersion Modeling
Caligiuri, Jim	Izaac Walton League	BMP
Carney, Kari	Iowa Citizens for Community Improvement	Air Emissions
Daniel, Chad	Iowa Department of Natural Resources	Dispersion Modeling
Donham, Kelley	The University of Iowa	BMP
Fitzsimmons, Catharine	Iowa Department of Natural Resources	All
Gieselman, Wayne	Iowa Department of Natural Resources	All
Hamilton, Heather	U.S EPA Region 7	All
Heinzen, Tarah	Sierra Club – Iowa Chapter	Air Emissions
Holm, Thomas	Izaac Walton League	Dispersion Modeling
Kielkopf, Ron	Iowa Citizens for Community Improvement	Air Emissions
Kuper, Marian	Iowa Citizens for Community Improvement	Dispersion Modeling
Lenfert, Carissa	Iowa Citizens for Community Improvement	BMP
McCasland, Jim	Iowa State Association of Counties	Air Emissions
McGraw, Jim	Iowa Department of Natural Resources	All
Nickey, Dan	Iowa Air Emissions Assistance Program	Air Emissions
O'Shaughnessy, Patrick	The University of Iowa	Dispersion Modeling
Pecchia, John	Iowa Department of Natural Resources	BMP
Pfeiffer, Dick	National Soil Tilth Laboratory	Air Emissions
Pins, Mel	Iowa Department of Natural Resources	Air Emissions
Powers, Wendy	Iowa State University	BMP
Schmitz, Stuart	Iowa Department of Public Health	BMP
Slager, Greg	Iowa State Association of Counties	BMP
Smith, Gary	Iowa Department of Natural Resources	BMP
Stein, Marnie	Iowa Department of Natural Resources	Air Emissions
Struckman, Sara	Iowa Citizens for Community Improvement	Dispersion Modeling
Thorne, Peter	The University of Iowa	Air Emissions
Walker-Rains, Wendy	Iowa Department of Economic Development	Dispersion Modeling
Xin, Hongwei	Iowa State University	Air Emissions

2.0 Best Management Practices

2.1 Introduction

There are a number of technologies and methods that have been designed to reduce odor and gas emissions from AFOs. Collectively, these technologies and methods are referred to as "best management practices" (bmp's). Bmp's are available to producers to reduce airborne emissions from livestock buildings, manure storage structures and manure application. Available bmp's may include chemical treatment, physical barriers or technologies and operational practices that can be implemented by the producer. For example, there are a variety of different products designed to cover earthen manure storage structures and trap gasses, thereby minimizing odor emissions. Recent studies have also shown that diet manipulation to reduce nutrient contents of manures may reduce gas emissions associated with manure storage and handling.

The DNR best management practices workgroup was charged with addressing the following issues related to bmps:

1. What types of bmp's are there to mitigate the emissions of pollutants from AFOs?
2. What is the effectiveness of the bmp's?
3. What are the associated costs (installation, maintenance, operation) of the bmp's?
4. What is the availability of the bmp's?
5. Will the bmp's have other environmental impacts that may need to be considered?
6. How should information be provided to producers on the availability of bmp's?
7. How will future technologies be approved and ranked?

The workgroup addressed these questions over the course of four meetings. During the meetings, it was identified that Iowa State University was in the process of publishing four fact sheets and associated flow charts on bmp's for reducing air emissions from AFOs. After review, the workgroup decided that these fact sheets addressed many of the issues and questions that the workgroup was assigned to review and were therefore adopted by the workgroup. The fact sheets have since been published. The fact sheets and flow charts are discussed below.

2.2 Bmp Fact Sheets

The Best Management Practices workgroup recommends adoption of the following four fact sheets:

PM 1970a	Practices to Reduce Odor from Livestock Operations
PM 1971a	Practices to Reduce Ammonia Emissions from Livestock Operations
PM 1972a	Practices to Reduce Hydrogen Sulfide from Livestock Operations
PM 1973a	Practices to Reduce Dust and Particulates from Livestock Operations

The fact sheets briefly describe the potential bmp's to reduce air pollutants from livestock operations. The fact sheets mention some potential drawbacks as well as benefits of each practice.

A producer would not be able to develop and implement one of the bmp's described in the fact sheet based solely on the information found in these publications. The fact sheets have been developed as an educational tool to make producers aware of scientifically proven practices. If a producer is interested in implementing one of these practices they would have to contact an expert such as representatives from either the Iowa State University Extension office, the United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS), equipment vendors, or private consultants who specialize in this area for details as they may pertain to their specific operation.

The bmp's found in the fact sheets (and associated flow charts) have been included only if scientific evidence supports the practice. There are many practices being marketed by private companies that do not yet have second party scientific evidence to support emission reduction claims, therefore, they have been excluded from these publications.

2.2.1 Practices to Reduce Odor from Livestock Operations

Document PM 1970a, contained on the following pages, is being used with permission from Iowa State University Extension.

Practices to Reduce Odor from Livestock Operations

Practices to control odor emissions associated with livestock production can be applied to animal housing areas, manure storage areas, and land where manure is applied. This document provides an overview of practices for each situation, highlights their advantages and disadvantages, and provides producers with sufficient information to make informed choices after evaluating production and economic aspects of their operations.

Odor Control Strategies for Livestock Housing

Odors generated in livestock housing can exit the facility and make their way to downwind neighbors. Even systems that utilize external manure storage will have some manure within the housing itself, creating odor. Additionally, there will be odors and dust particles from feed and animals themselves. Odorous compounds tend to be carried on dust particles and therefore, strategies to reduce odors from animal housing focus primarily on housekeeping measures that reduce dust emissions.

Filtration and Biofiltration

Some odors travel attached to particles. By effectively trapping particle emissions, odorous compounds can also be trapped. Mechanical filtration traps approximately 45 percent of particles between 5 and 10 µm and 80 percent of particles greater than 10 µm from animal housing areas. Mechanical filtration reduces the odor dilution threshold by 40 to 70 percent.

Biofilters trap particulates and also provide an environment for biological degradation of the trapped compounds. Biofilters have been developed to reduce odorous emissions from deep-pit, manure ventilation exhaust. Although mechanical filtration may be costly, biofiltration methods can inexpensively and effectively reduce exhaust odors. Biofiltration costs for a 700-head farrow-to-wean swine facility are estimated at $0.25 per piglet produced, amortized over a three-year life of the biofilter. Odor reductions at the facility exceeded 90 percent with similar reductions in hydrogen sulfide (90 percent) and ammonia emissions (74 percent). Similar odor and hydrogen sulfide reductions were observed using biofiltration on a dairy facility. The dust generated in a poultry facility, however, led to a poorer biofilter performance, with odor and hydrogen sulfide reductions of less than 40 percent.

Biofilters must be designed to provide suitable conditions for the growth of a mixture of aerobic bacteria within the biofilter. These bacteria will degrade the odorous compounds into less odorous end products. Oxygen concentration, temperature, residence time, and moisture content are among the parameters that must be considered when building a biofilter. Although management must be taken into consideration, it is clear that low-cost biofiltration systems ($150–200 per 1,000 cfm of air treated) can be implemented in livestock housing facilities.

Impermeable Barriers

Following the concept that odor is transmitted on dust particles, an alternative to filtering particles during air movement is to stop the movement altogether. Windbreak walls or air dams have proven effective in reducing both downwind dust particle concentrations and odor concentration. Windbreak walls have been constructed with 10-foot × 10-foot pipe frames and tarpaulins, and placed at the end of swine-finishing buildings, immediately downwind of the exhaust fans. Downwind dust and odor concentrations were reduced on demonstration facilities, in areas with the windbreak walls, due to plume deflection.

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University Extension

PM 1970a July 2004

Depending on the materials used for the barriers (tarpaulins on a frame or solid wood, for example) barrier life can be from a few years to decades before replacement is needed.

Oil Sprinkling

Coating surfaces to control dust has involved the use of vegetable oil, either sprayed or sprinkled in animal pens. A Minnesota study reported a 40 to 70 percent reduction in odor, following a detailed protocol for oil application. Hydrogen sulfide concentrations were reduced 40 to 60 percent in the oil-sprinkled rooms. No effect on ammonia concentration was observed. The practice involves safety issues such as the slippery conditions of pens and alleys following repeated oil applications. Costs are minimal for the vegetable oil, and other costs involve a sprayer and the labor needed for the daily oil application.

Landscaping

Landscaping can reduce the emission of housing odors, as well as odors generated by other components of the livestock operation, beyond the property line. Landscaping acts as a permeable filter for particle emissions, slowing particulate movement and diluting concentrations of emissions. Trees and shrubs act as biofilters for odorous compounds that are attached to fine particles. By landscaping with both a treeline and a row of shrubs, particles at various heights within a plume can be adsorbed. To maximize adsorption, landscape materials with large surface areas are recommended. Trees and shrubs placed around the facility cannot impede ventilation and are often located on the property lines.

Costs associated with landscaping will vary depending on selected trees and shrubs, and on perimeter size. Estimates of a shelterbelt planted around a 3,000-head hog facility using "higher"

cost trees ($25 per shrub or tree), calculated out to $0.68 per pig for one year, and amortized over 20 years at 5 percent, is just $0.09 per pig. These costs include maintenance costs. In addition to acting as a natural filtration system for odors, landscaping has the additional benefits of being aesthetically pleasing to the eye and of restricting the view of the operation. So, while documented effectiveness on emissions is scarce, the value of creating a facility that is pleasant to the eye cannot be underestimated.

Dietary Manipulation

An alternative to filtration of odors, as they leave housing facilities, is the reduction of the concentration of odorous emissions that can be produced upon anaerobic decomposition of the manure. Manipulation of livestock diets to alter excretion composition, and thus the odor of excretions, may be effective in housing areas. Swine studies have identified trends toward reducing odor intensity by reducing crude protein concentration. One study demonstrated reduced concentrations of odorous compounds when swine diets were formulated with crystalline amino acids, which caused a reduction in the dietary crude protein concentration. Odors should be reduced after altering the composition of manure and reducing the amount of odor precursors in it. Research to quantify reductions, after manure has been stored, are limited but some suggest as much as 20 percent odor reduction, when pigs are fed so as not to exceed their lysine and methionine requirements.

> Dietary manipulation can reduce manure odors prior to excretion . . .

Feedstuff selection may impact odor when manure is excreted or during manure storage. Studies with both pigs and dairy cattle demonstrated a trend of increasing odor intensity when diets contain higher concentrations of bloodmeal due to the amino acids that bloodmeal supplies in excess of animal needs when diets are formulated on a lysine basis only. Other studies have found that addition of peppermint to cattle diets improved odor of excreted manure. Fermentation characteristics of barley resulted in improved manure odor (25 percent reduction in odor intensity) compared to odor intensity from cattle fed sorghum diets.

Dietary manipulation can reduce manure odors prior to excretion as well as during manure storage, when anaerobic decomposition is taking place and odorous intermediate compounds are being formed. However, only a limited amount of research is currently available to indicate which diet regimens or ingredients cause odor reduction.

Reduced odor emissions . . . are the result of improved decomposition.

Odor Control Strategies for Manure Storage Facilities

Malodor (an odor that is undesirable) is the result of incomplete anaerobic decomposition of stored manure. During the decomposition process, malodorous intermediate compounds are produced and can accumulate if the populations of bacteria that degrade these compounds are insufficient. These accumulations result in odor nuisance. Following is a summary of practices that can be used to reduce odors from manure storage facilities.

Solids Separation

Solids separation by sedimentation, screening, filtration, or centrifugation allows for the removal of material that exceeds the screen-opening size. Often, in the case of ruminant manures, this is a fibrous material that resists decomposition during storage. By removing larger-sized material, thereby decreasing the loading rate, the life of the storage area can be extended. Decomposition of remaining stored material may benefit from removal of the poorly digestible material. Reduced odor emissions (intensity and concentration of odorants) from storage facilities are the result of improved decomposition. A 50 percent reduction in odor threshold from swine housing air samples was observed when a filter net was installed under the floor slats and daily removal of the solids collected on the net was conducted. This reduction may have been due, in large part, to the daily removal of material. Odor evaluation, following separation of dairy manure, showed no difference between separated and unseparated manure. Mechanical solids separators require a capital investment of $15,000 to $100,000. Typically, separation efficiency is much greater for ruminant manure because its particles are less uniform in size. Gravity settling (sedimentation) necessitates less capital investment but its impacts on odor reduction are undocumented.

Anaerobic Digestion

Anaerobic digestion enhances a naturally occurring process by providing conditions suitable for complete decomposition of organic matter to low-odor end products. During the process, manure is contained in a closed system, preventing release of odorous emissions to the atmosphere. The use of anaerobic digestion has proven very effective in reducing manure odors both during storage and during land application. As much as a 50 percent reduction in dairy manure odor intensity was observed using a 20-day retention time of material in the digesters. Although generally thought to be a capital-intensive system, some estimates illustrate that anaerobic digestion is economically feasible for larger operations. An example of a budget shows that a positive net income per cow of $31 per year can be realized if methane is captured and used as an energy source. The following economic information, based on a 3,000-head swine finishing facility, is provided: $1.10 (20-year life) to $4 per head (10-year life) for initial construction, minus gas harvesting equipment; $40 per head capacity to install and purchase gas harvesting equipment; $3 per head capacity recaptured as income from energy produced. However, return on investment is largely related to investment costs and resale value of the energy generated. Typically, the operation must be able to utilize the energy it generates for anaerobic digestion to be affordable. This limits its use, largely, to dairy operations and some larger breeding and gestation facilities.

The use of anaerobic digestion has proven very effective in reducing manure odors . . .

Additives

In a dilute manure handling system, bacterial populations are more likely to occur in quantities sufficient to provide a balanced production and utilization of intermediate degradation compounds. Addition of supplemental bacteria or enzymes may enhance the rate of processing because conditions are suitable for bacterial growth and function. Enzymatic or chemical additions are more likely to have a greater benefit on odor intensity in a dilute system than a slurry or solid system. Unpublished field reports indicate a direct relationship between lower levels of odor and the presence of anaerobic photosynthetic bacterial populations in lagoons. The anaerobic photosynthetic bacteria utilized many of the odorous compounds for bacterial growth. Reduced odor from lagoons where the pink-rose color is present, which is indicative of the populations, is likely the result of degradation and utilization of such odorous intermediates. Mode of action of many commercially available products remains unknown, but it is possible that some enzymes enhance biological decomposition of odorous compounds to less odorous end products. However, recommendations for modes of action or products that are routinely effective are not available.

Impermeable Covers

Covering a manure storage area with an impermeable cover prevents the release of odorous gases from manure storage into the atmosphere, and eliminates the effects of wind and radiation on emission rates. Odor reduction efficiencies of 70 to 85 percent have occurred, with reductions as great as 90 percent, when surfaces are completely covered by impermeable covers. Polyethylene covers typically range in price from $1.00 to $1.40 per square foot, installed. Wind and snow-load damage present the greatest challenges with respect to implementation of the extended use of impermeable covers. Damage due to weather alters the life of the cover, impacting the capital investment required over time. Many manufacturers list a useful life of 10 years if the storage area is constructed to prevent snow accumulation on the cover, but no guarantee against wind damage is provided.

Permeable Covers

Permeable covers, or biocovers, act as biofilters on the top of manure storage areas. Materials often used as covers include straws, cornstalks, peat moss, foam, geotextile fabric, and Leka rock. Permeable biocovers reduce odor, in part, by reducing both the radiation onto the manure storage surface and the wind velocity over the surface of the storage area. Covers act as a barrier to these forces. At the solution/air interface, humidity is relatively high, which creates a stabilized boundary that slows the emission rate of odorous volatiles. The aerobic zone within the biocover allows the growth of aerobic microorganisms that utilize carbon, nitrogen, and sulfur for growth. By further degrading and making use of these compounds prior to exiting the biocover, odors emitted above the biocover are altered and reduced. Reports of odor reductions of 40 to 50 percent are common when various straw materials are used. An 85 percent odor reduction efficiency was noted following the use of a floating mat or corrugated materials.

Chopped straw being applied to manure storage to act as a biocover.

Liquid swine manure in concrete pit covered with Leka rock.

Costs for biocovers vary widely depending on material used and method of application. In Minnesota, an operation employed a ⅛-inch thick geotextile material that cost $0.25 per square foot plus installation. Straw was added on top of the geotextile cover for additional odor control. Straws and cornstalks cost approximately $0.10 per square foot, applied; peat moss and foam cost about $0.26 per square foot, and Leka rock is approximately $2.50 per square foot for a 3-inch layer. Leka rock is a product of Norway, thereby requiring considerable shipping costs ($5 to $6/cubic foot). The cost to cover a 1.5-acre earthen storage was $6,000 while an above ground tank over 0.2 acre was $500, for the same material. Most recommendations suggest a minimum of 8-inch depth, preferably 10- to 12-inch depth of coverage on a manure storage surface. New covers (except Leka rock which may be a single application) need to be applied at least annually, as one study showed that only 50 percent of the straw cover remained four months after installation. Therefore, management and re-investment costs need to be considered. Removal of large, fibrous material during storage cleanout must also be considered before selecting this option.

Aeration

Because nuisance odor results from incomplete anaerobic processes, strategies to supply oxygen and maintain an aerobic environment can effectively control odor. Use of mechanical aerators on manure slurry or dilute manure storages will

Aerator on second-stage lagoon at swine facility will reduce hydrogen sulfide emissions, but may also increase ammonia emissions.

reduce odors substantially. However, capital investment and operating costs are considerable ($2 to $4 per pig marketed or $3,000 to $6,000 per aerator; often, more than one aerator is needed). Selection and size of an aerator or aeration system is critical to obtain the desired performance, so a consultant needs to be involved in the decision-making and planning processes. Systems that aerate only the top portion of manure storage, thus reducing cost, are under evaluation.

Aeration, by design, incorporates oxygen into the manure storage. Most commonly, mixing of the manure is used to introduce oxygen. During this process, N is volatilized to the atmosphere, primarily as ammonia. Therefore, aeration, although effective for reducing odor, can increase ammonia emission.

Composting

Composting can control odors because it maintains an aerobic environment in the manure. Disadvantages of composting include the high levels of management required to keep the process timely: minimal management leads to slow decomposition whereas intensive management can lead to quick decomposition. Another disadvantage is the need to bring in a bulking agent (newspaper, straw, wood chips) to maintain a balance of carbon to nitrogen (C:N) during the decomposition process. Loss of N to the atmosphere, primarily as ammonia, is a problem that needs to be weighed carefully when considering this option, particularly when controlling ammonia emissions is also an objective.

Composting beef manure.

Facilities should be covered to prevent runoff due to precipitation, and if built on a compacted area, it will prevent leaching of nutrients. Odor reduction benefits are not well documented, despite conventional thought that composting can be an effective control practice for odor. Costs include construction of the site with a compacted floor and roof, and continuous maintenance of the compost, which involves equipment of appropriate size to turn (aerate) the pile. For example, a 4-foot × 6-foot × 3-foot deep pile may be turned more properly with a small skid loader whereas a considerably larger pile would be better handled with a front-end loader.

Composting is a better option for operations that handle solid manure. Liquid systems will require some type of drying process or a large amount of bulking agents to avoid odor during the composting process.

Composting is a better option for . . . solid manure

Dry Manure Storage

In open lot facilities, dust and runoff control serve as the principal means by which odor from housing facilities is managed. Lots should allow for good drainage and producers should avoid unnecessary addition of water (e.g., overflowing waterers). Quite often, beef or dairy facilities that utilize open lots will house animals in facilities with bedded-packs. Control of odor from these housing facilities can best be achieved by maintaining a dry bedding area through proper maintenance of the packs. Adequate bedding must be added as a routine. Guidelines for management of these systems, appropriate amounts of bedding needed, and absorption capacities of various bedding materials, are available (MWPS-18, 1993).

Beef manure settling basin.

Strategies to Reduce Odors During Land Application

During land application of manure, producers are more likely to receive nuisance complaints. In addition to increased road traffic, manure spreading brings odors closer to nearby residents than when manure is in storage at the livestock facility. Therefore, measures to minimize odor nuisance during the time of manure application should be considered, in addition to odor control measures used during manure storage.

Injection and Incorporation

Injecting or incorporating manure shortly after surface application can best prevent odorous emissions that occur as result of land application. Estimated costs to inject manure are $.003 per gallon above the cost to haul and broadcast liquid manure. A portion of the added cost can be recaptured in the form of reduced nitrogen losses for injected manure versus broadcast application. Field tests in Iowa demonstrate odor reduction ranging from 50 to 75 percent with injection as compared to broadcast application. Based on these reports, greater benefits can be realized by incorporating manure after broadcast application.

Demonstration of injecting manure to help reduce ammonia emissions during land application.

Irrigation

Pivot irrigation systems can be a substantial source of downwind odor. Systems that spray close to the canopy can minimize dispersion of odorants by altering the dispersion plume. Nozzle selection may also contribute to improved odor control. Nozzles should be positioned to avoid application outside of property boundaries, and if possible, use low-rise, low-pressure or trickling systems to achieve maximum odor control of irrigated manure effluents. Systems that spray close to the canopy and employ appropriate nozzle position likely realize a uniform nutrient application as well. When pivot application is the most desirable means for nutrient application, careful timing of application will minimize nuisance.

Manure Additives

Manure additives have been widely debated as to their effectiveness in controlling odorous emissions. In general, there have not been any additives or classes of additives, so far identified, that routinely reduce odor during manure application. Costs are product-specific and often determined as much by application rate and frequency as by the cost per unit weight.

Timing of Application

Practices that do not involve physical changes to their existing operations should be implemented by producers. One such practice is timing of manure application. More frequent application and less time for manure storage is a more desirable practice from an odor control standpoint. However, best use of nutrients will occur when manure application coincides with the times when crops are most in need of manure nutrients. The compromise, then, is to apply manure in the

spring or fall, or both, and try to plan the applications when they will be least offensive to neighbors. Producers should avoid holidays and be aware of wind conditions so that their neighbors will be in the downwind direction as little time as possible. Notifying neighbors of manure application plans is also a very important strategy to be undertaken. Application in early evening, when air is still, is conducive to greater odor than at midday, when air is more turbulent, allowing odor to dissipate more readily.

Application in early evening when air is still, is conducive to greater odor than at midday . . .

Conclusions

Employing practices to control odor from livestock facilities can result in fewer nuisance concerns. Several practices are available but not all are suited for all operations. Careful consideration and selection of each practice will ensure the desired results. Regardless of the practice selected, common sense and consideration of neighbors are necessary components of a sound odor management plan.

Resources

For a list of research reports, ISU Extension publications, and links to current news regarding air quality and animal agriculture, please visit the Air Quality and Animal Agriculture Web page at: http://www.extension.iastate.edu/airquality.

PM 1970a *Practices to Reduce Odor from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1970a.pdf

PM 1971a *Practices to Reduce Ammonia Emissions from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1971a.pdf

PM 1972a *Practices to Reduce Hydrogen Sulfide from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1972a.pdf

PM 1973a *Practices to Reduce Dust and Particulates from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1973a.pdf

Prepared by Wendy Powers, environmental extension specialist, Department of Animal Science, Iowa State University. Reviewed by David Schmidt, extension engineer, University of Minnesota. Edited by Marisa Corzanego, extension communications intern, Communication Services, Iowa State University Extension. Designed by Jane Lenahan, graphic designer, Instructional Technology Center, Iowa State University.

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2.2.2 Practices to Reduce Ammonia Emissions from Livestock Operations

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Practices to Reduce Ammonia Emissions from Livestock Operations

Practices to control ammonia emissions associated with livestock production can be applied to animal housing, manure and compost storage areas, and land where manure is applied. This document provides an overview of control practices for each situation, highlights their advantages and disadvantages, and allows producers to make informed choices after evaluating production and economic aspects of their operations. Note that **not all practices that control ammonia emission will result in odor control and vice versa, even though ammonia is certainly associated with livestock production.**

Ammonia Emission Control Strategies for Livestock Housing

In livestock facilities, ammonia results primarily from the breakdown of urea (present in urine) by the enzyme urease (excreted in feces). In poultry, urease is excreted with uric acid. Undigested feed protein and wasted feed are additional sources of ammonia in animal production systems. Strategies to reduce ammonia from animal housing focus primarily on preventing ammonia formation and volatilization, or downwind transmission of ammonia after it is volatilized. Four practices used to control ammonia emission from livestock housing are discussed below.

Filtration and Biofiltration

Filters trap particles and emissions, whereas biofilters not only trap emissions but also provide an environment for aerobic biological degradation of trapped compounds. Biofilters have been developed primarily to reduce emissions from the deep-pit manure ventilation exhausts, and, to a lesser extent, from the building exhaust. Although mechanical filtration may be costly, biofiltration can effectively and inexpensively reduce exhaust odors. Biofiltration costs for a 700-head farrow-to-wean swine facility are estimated at $0.25 per piglet, amortized over a 3-year life of the biofilter. Reductions of ammonia emission at that operation are approximately 74 percent, whereas reductions in both hydrogen sulfide and odor emissions are about 90 percent.

Biofilters must be designed to provide suitable conditions for the growth of a mixture of aerobic bacteria within the biofilter. These bacteria will degrade the odorous compounds, including ammonia. Oxygen concentration, temperature, residence time, and moisture content are among the parameters that must be considered when building a biofilter. Although management must be taken into consideration, it is clear that low-cost biofiltration systems ($150—200 per 1,000 cfm of air treated) can be implemented in livestock housing facilities that are mechanically ventilated and can contribute to greater efficiency of the operation.

Impermeable Barriers

An alternative to filtering particles and gases during air movement is to stop the movement altogether. Windbreak walls or air dams have proven effective in reducing both downwind dust particle concentrations and odor concentration. As a consequence of the presence of impermeable barriers, one might expect a reduction in ammonia concentrations. However, no scientific data is available so far to support this argument. Windbreak walls have been constructed with 10-foot × 10-foot pipe frames and tarpaulins, and placed at the end of swine-finishing buildings, immediately downwind of the exhaust fans. Downwind dust and odor concentrations were reduced on demonstration facilities, in areas with windbreak walls, due to plume deflection.

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The kind of materials used for the barriers (tarpaulins on a frame or solid wood, for example) will determine the life of barriers, which can be from a few years to decades before replacement is needed.

Landscaping

Landscaping may reduce both housing emissions and emissions generated by other components of the livestock operation, beyond the property line. Landscaping acts as a permeable filter for particle emissions, slowing the emission movement and diluting the concentrations of emissions. Trees and shrubs act as biofilters for fine particles. By landscaping with both a tree line and a row of shrubs, particles at various heights within a plume can be adsorbed. To maximize adsorption, landscape materials with large surface areas are recommended. Trees and shrubs placed around the facility cannot impede building ventilation and are often located on the property limits.

Costs associated with landscaping will vary depending on selected trees and shrubs, and on perimeter. Estimates of a shelterbelt planted around a 3,000-head hog facility using "higher" cost trees ($25 per shrub or tree), is $0.68 per pig for one year. Amortized over 20 years at 5 percent, and including maintenance costs, the estimate is only $0.09 per pig. In addition to acting as a natural filtration system, landscaping has the additional benefits of being aesthetically pleasant to the eye and of restricting the view of the operation. So, while documented effectiveness on emissions is scarce, the value of creating a facility that is pleasant to the eye cannot be underestimated. However, the time between the planting of immature trees and the time when those trees are large enough to be effective must be considered before producers decide on the best practice for their systems. In Iowa, this time lag may be as long as seven years, depending on the planting varieties.

Dietary Manipulation

Minimization of nitrogen (N) excretion is the most obvious method to curb ammonia emissions. By reducing the amount of nitrogen excreted, less ammonia will be formed and volatilized. When common feeds are included in the diet, protein sources are added to meet animal needs for lysine, typically the most limiting amino acid. All other amino acids are consequently supplied in excess and excreted.

The most promising dietary manipulation consists of supplying non-ruminants with the amino acids they need, including crystalline ones, instead of supplying feeds based on crude protein. In the ruminant animal, meeting the needs of the rumen, independently of the lower digestive tract, effectively reduces the content of dietary crude protein. In swine, dairy, and poultry, nitrogen excretion is reduced by approximately 8.5 to 10 percent for each one-percentage unit reduction in dietary crude protein. Greater reductions are possible and, in fact, direct emissions of ammonia are reduced by 19 percent for every percentage unit of dietary crude protein that is reduced in swine diets. As animals are fed closer to true nitrogen requirements, further reductions in dietary protein may result in less pronounced reduction in nitrogen excretion and ammonia losses.

> By reducing the amount of nitrogen excreted, less ammonia will be formed and volatilized.

Addition of fermentable carbohydrates, such as bran or pulp, into grow-finishing diets, resulted in a 14 percent reduction of ammonia emission for each increase in carbohydrate. More work evaluating the balance of carbohydrate and protein in diets is needed. The reduction may be due to a pH effect, to the shift from urinary to fecal nitrogen excretion, or both. Additives that bind ammonia have shown reductions in ammonia emission (26 percent over a period of seven weeks in swine fed a yucca extract).

Lysine is economical for both swine and poultry diets. By-products are important and economical sources of rumen bypass protein for ruminants. Therefore, some dietary strategies do not increase diet costs to the producer. Further protein reductions will increase ration cost but may be considered affordable, depending on the operational objectives of each producer.

Ammonia Emission Control Strategies for Manure Storage Facilities

In the air, ammonia can combine with other gases to form ammonium nitrate and ammonium sulfate, which are fine particulates. These particulates are of concern for human health and are regulated under the Clean Air Act. Therefore, minimizing the release of ammonia from animal feeding operations is desirable. Similar to housing strategies, strategies to reduce ammonia from animal housing focus primarily on preventing ammonia formation and volatilization or downwind transmission of ammonia, after it is volatilized. A summary of practices to reduce ammonia from manure storage facilities is provided below.

> . . . particulates are of concern for human health.

Impermeable Covers

Covering a manure storage area with an impermeable cover prevents the release of gases into the atmosphere, and eliminates the effects of wind and radiation on emission rates. Odor reduction efficiencies of 70 to 85 percent have been observed when surfaces are completely covered by impermeable covers. Although undocumented, ammonia reductions may be similar. Polyethylene covers typically range in price from $1.00 to $1.40 per square foot, installed. Wind and snow-load damage present the greatest challenges with respect to implementation and extended use of impermeable covers. Damage due to weather alters the life of the cover and impacts the requirements for capital investment over time. Many manufacturers list a useful life of 10 years for facilities constructed to prevent snow accumulation on the cover, but do not provide any guarantee against wind damage.

Permeable Covers

Permeable covers, or biocovers, act as biofilters on the top of manure storage areas. Materials often used as covers include straw, cornstalks, peat moss, foam, geotextile fabric, and Leka rock. Permeable biocovers reduce emissions, in part, by reducing both the radiation onto the manure storage surface and the wind velocity over the liquid surface of the storage area. At the solution/air interface, humidity is relatively high, which creates a stabilized boundary that slows the emission rate of odorous volatiles. The aerobic zone within the biocover allows the growth of aerobic microorganisms that utilize the carbon, nitrogen, and sulfur from the emissions for growth. By further degrading and making use of these compounds prior to exiting the biocover, odors emitted from the biocover are altered and reduced. Reports of odor reductions of 40 to 50 percent are common whenever various straw materials are used. An odor reduction efficiency of 85 percent has been noted following the use of a floating mat or corrugated materials. Although ammonia emission reductions are undocumented, the processes that occur in the biocovers suggest that ammonia emissions may be reduced to the same extent.

Liquid swine manure in concrete pit covered with Leka rock.

Costs for biocovers vary widely depending on the material used and the method of application. In Minnesota, an operation employed a ⅛-inch thick geotextile material that cost $0.25 per square foot, plus installation costs. Straw was added on top of the geotextile cover for additional odor control. Straws and cornstalks cost approximately $0.10 per square foot, applied; peat moss and foam cost about $0.26 per square foot, and Leka rock is approximately $2.50 per square foot for a 3-inch depth. All costs depend on the depth of the material used. Leka is a product of Norway, thereby requiring considerable shipping costs of $5—$6 per cubic foot. The cost to cover a 1.5-acre earthen storage was $6,000 whereas an above ground tank over 0.2 acre was $500, for the same material.

Most recommendations suggest a minimum of 8-inch and preferably 10- to 12-inch depth of coverage on a manure storage surface. New covers (except Leka rock) may need to be applied at least annually, and one study showed that only 50 percent of the straw cover remained four months after installation. Therefore, management and re-investment costs need to be considered. Removal of large, fibrous material during storage cleanout must also be considered before selecting this option. One disadvantage of both permeable and impermeable covers is a probable increase in ammonia emissions and odors during land application.

Mineral and chemical amendments have been used to reduce ammonia emissions from animal manures.

Urine/feces Segregation

Because ammonia results from the interaction of urine and feces in swine and ruminants, efforts to separate them immediately upon excretion have reduced ammonia emissions successfully. Manure handling systems designed to prevent urease from coming in contact with urea are under investigation. Most systems employ a separator or a belt conveyor whereby feces, containing urease, are captured on the belt and urine is stored below. As much as 80 percent reduction in ammonia emissions is expected from using this system but the practice has not yet been commercially implemented. However, several urine/feces segregation systems are in the developmental phase at this time.

Acidification

Depending on the pH, N can exist in different forms. Reducing the pH maintains more nitrogen in the form of ammonium, which is not released as a gas. Therefore, strategies that acidify manure (reducing the pH) can be used to trap ammonium and prevent its release as ammonia. Among these strategies are dietary practices used to acidify urine by including phosphoric acid. However, ammonia emissions are more related to the buffering capacity, or alkalinity, of the manure than to pH, suggesting that pH of excretions may increase during storage, therefore reducing the effectiveness of this strategy. A disadvantage of acidification is that although it traps ammonia, the reduced pH is conducive to volatilization of hydrogen sulfide, another odorous compound produced from the anaerobic decomposition of manure. Costs associated with this practice include the acid and the equipment to apply and mix the acid with the stored manure.

Additives

Additives to control ammonia emission predominantly function by either binding ammonia or by inhibiting urease, the enzyme that breaks urea down to ammonia. Two inhibitors, thiophosphoric triamide and cyclohexylphosphoric triamide, restrained the production of urease following application to cattle feedlot pens (0.32 oz. per pound of manure). Similarly, weekly additions of phenyl phosphorodiamidate to cattle and swine slurries prevented the urea from being hydrolyzed up to 70 and 92 percent, respectively. Because urease occurs widely in nature, the inhibitor must be applied routinely to prevent future emissions. Routine application, however, may pose problems once the manure is land-applied, unless plants can quickly use the nitrogen. Urease inhibitors are not widely available commercially, and the above-mentioned compounds are chemical rather than products. However, one product, manufactured by Agrotain, is distributed throughout the United States.

. . . dry manure, ammonia control can be a greater challenge.

Mineral and chemical amendments have been used to reduce ammonia emissions from animal manures. Phosphates and gypsum reduced ammonia losses from dairy manure storage by 28 and 14 percent, respectively. Triple superphosphate, superphosphate, calcium chloride, and gypsum treatments reduced ammonia losses by 33, 24, 13, and 8 percent, respectively, when surface-applied to dairy manure. All additives involve the cost of the products themselves and the application equipment associated with them. Continuous application is likely needed in manure storage whereas a single application of the additive may suffice during manure application if manure is then incorporated.

Dry Manure Storage

In open lot facilities and facilities that store dry manure, ammonia control can be a greater challenge. Ammonia loss during composting depends on the carbon to nitrogen (C:N) ratio: ammonia volatilization is significant below 15:1. Increased use of bedding will help maintain a higher C:N ratio but also results in a dryer product that will not compost as readily without the addition of moisture. Application of a layer of 38 percent zeolite, placed on the surface of the composting poultry manure, reduced ammonia losses by 44 percent.

Strategies that focus on source reduction, such as diet manipulation, are applicable and may prove to be the best control measure. Covering manure can be effective as well. Similarly, practices that involve binding ammonia or altering the pH, so that ammonia is less volatile, can control its emission. Calcium chloride and triple superphosphate treatments are effective in reducing losses when surface applied to poultry manure (19 and 17 percent, respectively).

Strategies to Reduce Ammonia Emissions During Land Application

Estimates of whole-farm ammonia emissions suggest that as much as 35 percent of the total ammonia emissions may occur during land application of manure. Therefore, control strategies beyond those implemented in housing and manure storage areas should be considered, as reported below for injection and manure amendments.

Injecting manure can reduce ammonia emissions during land application.

Injection or Incorporation

Injecting or incorporating manure shortly after surface application can best prevent nitrogenous emissions that result from land application, in addition to reducing odorous emissions. Costs to inject manure are estimated to be $0.003 per gallon above the cost to haul and spread liquid manure. A portion of the added cost can be recaptured, agronomically, in the form of reduced nitrogen losses for injected manure versus broadcast application. The benefits of reduced nitrogen losses through volatilization can also be realized by incorporation, after broadcast application.

Closeup of injectors.

Manure Amendments

Research has demonstrated that some products can effectively reduce ammonia losses through either a binding or a pH effect. Urease inhibitors may also prove effective. Costs are product-specific, and often determined as much by application rate and frequency as by the cost per unit weight. Following land application of fresh chicken slurry amended with calcium chloride, a reduction in ammonia losses of 37 percent was found. Aluminum sulfate, ferrous sulfate, and phosphoric acid reduced ammonia volatilization from litter by 96, 79, and 93 percent, respectively. Aluminum sulfate is often recommended as amendment, due to the enhanced phosphorus content of litter following addition of phosphoric acid, and to toxicity concerns associated with addition of ferrous sulfate.

Conclusions

Employing specific practices can reduce ammonia emissions. A number of practices are available but not all are suited for all operations. Careful consideration and selection will help ensure that you achieve the desired results.

Neither endorsement of companies or products mentioned is intended, nor is criticism implied of similar companies or products not mentioned.

Resources

For a list of research reports, ISU Extension publications, and links to current news regarding air quality and animal agriculture, please visit the Air Quality and Animal Agriculture Web page at: http://www.extension.iastate.edu/airquality.

PM 1970a *Practices to Reduce Odor from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1970a.pdf

PM 1971a *Practices to Reduce Ammonia Emissions from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1971a.pdf

PM 1972a *Practices to Reduce Hydrogen Sulfide from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1972a.pdf

PM 1973a *Practices to Reduce Dust and Particulates from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1973a.pdf

Prepared by Wendy Powers, environmental extension specialist, Department of Animal Science, Iowa State University. Reviewed by David Schmidt, extension engineer, University of Minnesota. Edited by Marisa Corzanego, extension communications intern, Communication Services, Iowa State University Extension. Designed by Jane Lenahan, graphic designer, Instructional Technology Center, Iowa State University.

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2.2.3 Practices to Reduce Hydrogen Sulfide from Livestock Operations

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Practices to Reduce Hydrogen Sulfide from Livestock Operations

Practices to reduce hydrogen sulfide emissions associated with livestock production apply to animal housing, manure storage areas, and land where manure is applied. This document provides an overview of practices for each situation, highlights their advantages and disadvantages, and allows producers to make informed choices after evaluating production and economic aspects of their operations. Note that **not all practices that achieve hydrogen sulfide emission control will result in odor control and vice versa, even though hydrogen sulfide is certainly an odorant associated with livestock production.**

Hydrogen Sulfide Control Strategies for Livestock Housing

Gases generated in livestock housing facilities can exit the facility and make their way to downwind neighbors. Even systems that utilize external manure storage will have some manure within the housing itself, which may lead to gaseous emissions. Strategies to decrease hydrogen sulfide emissions from animal housing focus primarily on reducing the formation and movement of sulfur compounds. Five practices used to control hydrogen sulfide emission from livestock housing are discussed below.

Filtration and Biofiltration

Filters function by trapping particles and emissions. Biofilters not only trap emissions but also provide an environment for aerobic biological degradation of trapped compounds. Biofilters have been developed to reduce emissions from deep-pit manure ventilation exhaust, and, to a lesser extent, from the building exhaust. Although mechanical filtration may be costly, biofiltration can be a low-cost means of effectively reducing exhaust odors. Biofiltration costs for a 700-head farrow-to-wean swine facility are estimated

at \$0.25 per piglet, amortized over a 3-year life of the biofilter. Hydrogen sulfide reductions at that operation exceeded 90 percent, and similar reductions occur in odor (90 percent) and ammonia emissions (74 percent). Similar hydrogen sulfide and odor reductions were observed using biofiltration on a dairy facility. Because of the dust generated in the building, biofilter performance on a poultry facility was poorer (< 40 percent hydrogen sulfide and odor reduction).

Biofilters must be designed to provide suitable conditions for the growth of a mixture of aerobic bacteria within the biofilter. These bacteria will degrade the odorous compounds to less odorous end products. Oxygen concentration, temperature, residence time, and moisture content are among the parameters that must be considered when building a biofilter. Although management must be taken into consideration, it is clear that low-cost biofiltration systems (\$150 to \$200 per 1,000 cfm of air treated) can be implemented in livestock housing facilities using mechanical ventilation.

Impermeable Barriers

An alternative to filtering particles during air movement is to stop the movement altogether. Windbreak walls or air dams have proven effective in reducing downwind dust particle concentrations and odor

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concentration. However, no data is currently available regarding hydrogen sulfide. Windbreak walls have been constructed with 10-foot × 10-foot pipe frames and tarpaulins, and placed at the end of swine-finishing buildings, immediately downwind of the exhaust fans. Downwind dust and odor concentrations were reduced on demonstration facilities, in areas with windbreak walls, due to plume deflection. Depending on the materials used for the barriers (tarpaulins on a frame or solid wood, for example) the life of the barrier could be from a few years to decades before replacement is needed.

Oil Sprinkling

Coating surfaces to control emissions and dust has involved the use of vegetable oil, either sprayed or sprinkled in animal pens. Data from a Minnesota study showed that hydrogen sulfide reductions were 40 to 60 percent in the oil-sprinkled rooms, following a detailed protocol for oil application. There was a 40 to 70 percent reduction in odor, but no effect on ammonia concentration was observed. Oil sprinkling involves safety issues such as the slippery conditions of pens and alleys following repeated oil applications. Costs are minimal for the vegetable oil, and other costs involve a sprayer and labor for the daily oil application.

Landscaping

Landscaping may reduce the emission of housing odors, as well as odors generated by other components of the livestock operation, beyond the property line. Landscaping acts as a permeable filter for particle emissions, slowing the particulate movement and diluting the concentrations of emissions. Trees and shrubs act as biofilters for odorous compounds that are attached to fine particles. By landscaping with both a treeline and a row of shrubs, particles at various heights within a plume can be adsorbed. To maximize adsorption, landscape materials with large surface areas are recommended. Trees and shrubs placed around the facility should not

impede building ventilation and therefore are often located on the property lines. Costs associated with landscaping will vary depending on selected trees and shrubs, and on perimeter size. The estimate of a shelterbelt planted around a 3,000-head hog facility using “higher” cost trees ($25 per shrub or tree), calculated as $0.68 per pig for one year, amortized over 20 years at 5 percent, is just $0.09 per pig. These costs include maintenance costs. In addition to acting as a natural filtration system for odors, landscaping has the additional benefits of being aesthetically pleasing to the eye and of restricting the view of the operation. So, while documented effectiveness on emissions is scarce, the value of creating a facility that is pleasant to the eye should not be underestimated.

Landscaping may reduce the emission of housing odors . . .

Dietary Manipulation

An alternative to filtration of emissions, as they leave housing facilities, is the reduction of the concentration of precursors to emissions. These precursors are produced upon anaerobic decomposition of the manure. Therefore, manipulation of livestock diets to alter excretion composition, and thus emission potential, may be effective in housing areas. Swine studies have identified trends toward reducing hydrogen sulfide concentration by reducing crude protein concentration and mineral sources that contain sulfur. For example, calcium oxide instead of calcium sulfate should be used, where possible, to reduce sulfur content in excretions. Nonetheless, research to quantify reductions is limited. However, some results suggest a reduction of as much as 40 percent in hydrogen sulfide concentration when

pigs are fed only the required amount of sulfur. Long-term storage effects on hydrogen sulfide emissions from manure are not currently available.

Producers also need to consider the sulfur content of the water supply. In some regions, water consumption means considerable sulfur intake by animals. To avoid overfeeding of sulfur, test the water supply and subtract the mass of sulfur consumed via water intake from the total daily sulfur needs. Excess sulfur will ultimately be excreted. Dietary manipulation can reduce manure sulfur content not only prior to excretion but also during manure storage, when anaerobic decomposition is taking place and reduced sulfur compounds are being formed. A limited amount of research is currently available to indicate which diet regimens or ingredients lead to the reduction of hydrogen sulfide.

Hydrogen Sulfide Control Strategies for Manure Storage Facilities

Hydrogen sulfide forms when manure is stored anaerobically. During the decomposition process, malodorous (offensive odors), intermediate compounds are produced and can accumulate if insufficient populations of bacteria that degrade these compounds are present. The summary below contains the recommended management practices that can be employed to reduce the emission of hydrogen sulfide from manure storage facilities.

Impermeable Covers

Covering a manure storage area with an impermeable cover prevents the release of gases into the atmosphere, and eliminates the effects of wind and radiation on emission rates. Although documented effectiveness for reducing hydrogen sulfide emissions is not available, impermeable covers are used to block any gas transfer, suggesting that emission reductions should be high and similar to those observed with odor (70 to 85 percent). Polyethylene covers typically range in price from $1.00 to $1.40 per square foot, installed.

Wind and snow-load damage present the greatest challenges with respect to implementation of the extended use of impermeable covers. Damage due to weather alters the life of the cover, impacting the capital investment required over time. Many manufacturers list a useful life of 10 years for storage areas constructed to prevent snow accumulation on the cover, but do not provide any guarantee against wind damage.

Permeable Covers

Permeable covers, or biocovers, act as biofilters on the top of manure storage areas. Materials often used as covers include straws, cornstalks, peat moss, foam, geotextile fabric, and Leka rock. Permeable biocovers reduce emissions, in part, by reducing both the radiation onto the manure storage surface and the wind velocity over the surface of the storage area. Covers act as a barrier to these forces. At the solution/air interface, humidity is relatively high, which creates a stabilized boundary that slows the emission rate of odorous volatiles. The aerobic zone within the biocover allows the growth of aerobic microorganisms that utilize carbon, nitrogen, and sulfur for growth. This aerobic zone should also curtail the formation of reduced sulfur compounds, such as hydrogen sulfide. Reported reductions in hydrogen sulfide emissions have not been found; however, reports of odor reductions of 40 to 50 percent are common when various straw materials are used. An odor reduction efficiency of 85 percent has been noted following the use of a floating mat or corrugated materials.

> Permeable biocovers reduce emissions . . .

Liquid swine manure in concrete pit covered with Leka rock.

Costs for biocovers vary widely depending on the material used and the method of application. In Minnesota, an operation employed a ⅛-inch thick geotextile material that cost $0.25 per square foot, plus installation. Straw was added on top of the geotextile cover for additional emission control. Straws and cornstalks cost approximately $0.10 per square foot, applied annually; peat moss and foam cost about $0.26 per square foot, applied annually; and Leka rock costs in excess of $2.50 per square foot for a 3-inch layer, but only has to be applied one time. Leka rock is a product of Norway, thereby requiring considerable shipping costs ($5 to $6 per cubic foot). The cost to cover a 1.5-acre earthen storage was $6,000 whereas an above ground tank over 0.2 acre was $500, for the same material.

Cover depth is very important for permeable covers. Most recommendations suggest a minimum of 8-inch depth, preferably 10- to 12-inch depth of coverage on a manure storage surface. Leka rock needs to be at least 3- to 4-inch deep. New covers (except Leka rock) need to be applied at least annually, and one study showed that only 50 percent of the straw cover remained four months after installation. Therefore management and re-investment costs need to be considered. Removal of large, fibrous material during storage cleanout must also be considered before selecting this option.

Aeration, by design, incorporates oxygen into the manure storage.

Aeration

Because hydrogen sulfide results from anaerobic processes, strategies to supply oxygen and maintain an aerobic environment can be effective in controlling the formation and emission of hydrogen sulfide. Capital investment and operating costs are considerable ($2 to $4 per pig marketed or $3,000 to $6,000 per aerator; often, more than one aerator needed). Selection and size of an aerator or aeration system is critical to obtain the desired performance, so a consultant needs to be involved in the decision-making and planning processes. Systems that aerate only the top portion of manure storages, which reduce costs, are under evaluation.

Aerator on second-stage lagoon at swine facility will reduce hydrogen sulfide emissions, but may also increase ammonia emissions.

Aeration, by design, incorporates oxygen into the manure storage. Most commonly, mixing of the manure is used to introduce oxygen. During this process, nitrogen is volatilized to the atmosphere, primarily as ammonia. Therefore, aeration, although effective for decreasing hydrogen sulfide, can increase ammonia emissions.

Composting

Composting can control hydrogen sulfide from solid manure because it maintains an aerobic environment in the manure. Hydrogen sulfide reduction benefits are not well documented. Disadvantages of composting include the high levels of management required to keep the process timely:

Composting beef manure.

minimal management leads to slow decomposition, whereas intensive management can lead to quick decomposition. Another disadvantage is the need to bring in a bulking agent (newspaper, straw, wood chips) to maintain a balance of carbon and nitrogen during the decomposition process. Loss of nitrogen to the atmosphere, primarily as ammonia, is a problem that needs to be weighed carefully when considering this option, particularly when controlling ammonia emissions is also an objective.

Facilities should be covered to prevent runoff due to precipitation, and storage on a compacted area will prevent leaching of nutrients. Composting costs involve construction of the site with compacted floor and roof, and continuous maintenance of the compost with appropriate equipment to turn and aerate the pile. For example, a 4-feet × 6-feet × 3-feet-deep pile may be turned more properly with a small skid loader, whereas a considerably larger pile could be better handled with a front-end loader.

Composting is a better option for operations that handle solid manure. Liquid systems will require either some type of drying process or a large amount of bulking agents to avoid problems during the composting process.

Dry Manure Storage

Hydrogen sulfide is not typically associated with systems that handle dry manure. Management to maintain the dry conditions, preventing anaerobic activity from occurring, is essential to prevent the formation of hydrogen sulfide.

Strategies to Reduce Hydrogen Sulfide During Land Application

During land application of manure, producers may be more likely to receive nuisance complaints. In addition to increased road traffic, manure spreading brings odors closer to nearby residents than when manure is stored at the livestock facility. Therefore, measures to minimize nuisance during time of application should be considered, in addition to measures that control hydrogen sulfide during manure storage.

Injection or Incorporation

Injecting or incorporating manure shortly after surface application can best prevent odorous emissions that occur as result of land application. Estimated costs to inject manure are $0.003 per gallon above the cost to haul and broadcast liquid manure. A portion of the added cost can be recaptured in the form of decreased nitrogen losses for injected manure versus broadcast application. Although hydrogen sulfide impacts have not been documented, field tests in Iowa demonstrate odor reduction ranging from 50 to 75 percent with injection as compared to broadcast application. Similar results would be anticipated for hydrogen sulfide. Based on these reports, great benefits can be realized by incorporating after broadcast application as well.

Injecting manure can reduce ammonia emissions during land application.

Timing of Application

Practices that do not involve any physical changes to their existing operations should be implemented by producers. One such practice is timing of manure application. More frequent manure application and therefore less storage time is most desirable from the standpoint of emissions control. However, to make best use of nutrients, manure application should coincide with the time when crops are most in need of manure nutrients. The compromise, then, is to apply manure in the spring and in the fall, or in both seasons, but plan the applications for those times when they will be least offensive to neighbors. Producers should avoid holidays and be aware of wind conditions, so that neighbors will be in the downwind direction as little time as possible. Application in early evening, when air is still, is conducive to greater emissions than at midday, when air is more turbulent, allowing odor and other gases to dissipate more readily. Notifying neighbors of manure application plans is also a very important strategy to be undertaken.

> . . . common sense and consideration of neighbors are necessary components of a sound odor management plan.

Conclusions

Several practices to control hydrogen sulfide from livestock facilities are available. However, not all practices are suited for all operations. Careful consideration and selection of each practice will ensure the desired results. Regardless of the practice selected, common sense and consideration of neighbors are necessary components of a sound odor management plan.

Resources

For a list of research reports, ISU Extension publications, and links to current news regarding air quality and animal agriculture, please visit the Air Quality and Animal Agriculture Web page at: http://www.extension.iastate.edu/airquality.

PM 1970a *Practices to Reduce Odor from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1970a.pdf

PM 1971a *Practices to Reduce Ammonia Emissions from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1971a.pdf

PM 1972a *Practices to Reduce Hydrogen Sulfide from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1972a.pdf

PM 1973a *Practices to Reduce Dust and Particulates from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1973a.pdf

Prepared by Wendy Powers, environmental extension specialist, Department of Animal Science, Iowa State University. Reviewed by David Schmidt, extension engineer, University of Minnesota. Edited by Marisa Corzanego, extension communications intern, Communication Services, Iowa State University Extension. Designed by Jane Lenahan, graphic designer, Instructional Technology Center, Iowa State University.

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2.2.4 Practices to Reduce Dust and Particulates from Livestock Operations

Document PM 1973a, contained on the following pages, is being used with permission from Iowa State University Extension.

Practices to Reduce Dust and Particulates from Livestock Operations

Practices to control particulate and dust emissions associated with livestock production can be applied to animal housing and manure storage areas. This document provides an overview of various practices for each situation, highlights their advantages and disadvantages, and allows producers to make informed choices after evaluating production and economic aspects of their operations.

Dust and Particulate Control Strategies for Livestock Housing

Dust and particulate matter (PM) generated in livestock housing can exit the facility and make its way to downwind neighbors. Within the housing area, dust particles from the feed and the animals themselves will be present. Reducing dust and PM from animal housing will contribute to improved odor conditions because some portion of odor is carried on dust particles.

Filtration and Biofiltration

Filtration serves as a mechanism for trapping dust and particulates. Mechanical filtration traps approximately 45 percent of particles between 5 and 10 μm, and 80 percent of particles greater than 10 μm from animal housing areas. Mechanical filtration reduces the odor dilution threshold by 40 to 70 percent. The odor dilution threshold is defined as the concentration at which 50 percent of a human panel can identify the presence of an odor or odorant without characterizing the stimulus. Biofilters trap particulates and also provide an environment for biological degradation of trapped compounds, contributing to odor reduction beyond that accounted for by dust removal alone. Although mechanical filtration may be costly, biofiltration can be a low-cost means for effectively reducing exhaust dust. Biofiltration costs, at a 700-head farrow-to-wean swine facility, are estimated at $0.25 per piglet produced, amortized over a 3-year life of the biofilter. Odor reductions at the operation exceeded 90 percent with similar reductions in hydrogen sulfide (90 percent) and ammonia emissions (74 percent). Similar odor and hydrogen sulfide reductions were observed using biofiltration on a dairy facility. Performance in a poultry facility, however, was poorer, with an odor and hydrogen sulfide reduction of less than 40 percent, likely due to the volume of dust present in the facility.

Biofilters must be designed to provide suitable conditions for the growth of a mixture of aerobic bacteria within the biofilter. Oxygen concentration, temperature, residence time, and moisture content are among the parameters that must be considered when building a biofilter. Although management must be taken into consideration, it is clear that low-cost biofiltration systems ($150 to $200 per 1,000 cfm of air treated) can be implemented in livestock housing facilities.

Installed biofilter at a swine facility.

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Impermeable Barriers

Following the concept that odor is transmitted on dust particles, an alternative to filtering particles from the exhaust air is to decrease the concentration of odors downwind by impeding their movement altogether. Windbreak wall or air dam designs have proven effective in reducing both downwind dust particle concentrations and odor concentration. Windbreak walls have been constructed with 10-foot × 10-foot pipe frames and tarpaulins, and placed at the end of swine-finishing buildings, immediately downwind of the exhaust fans. Downwind dust and odor concentrations were reduced on demonstration facilities, in areas with the windbreak walls, due to plume deflection. The materials used for the barriers (tarpaulins on a frame or solid wood, for example) determine the barrier life, which may be from a few years to decades before replacement is needed.

Oil Sprinkling

Coating surfaces to control dust has involved the use of vegetable oil, which is either sprayed or sprinkled in animal pens. Effectiveness in reducing dust concentrations is not documented. However, a Minnesota study reported a 40 to 70 percent reduction in odor following a detailed protocol for oil application. Hydrogen sulfide concentrations were reduced 40 to 60 percent in the oil-sprinkled rooms. No effect on ammonia concentration was observed. Oil sprinkling involves safety issues, such as the slippery conditions of pens and alleys, following repeated application. Costs are minimal for the vegetable oil, and other costs involve a sprayer and the labor needed for the daily oil application.

Landscaping

Landscaping can reduce downwind concentration of housing dust and odors, beyond the property line, by trapping and treating particle and gas emissions. Trees and shrubs act as biofilters for fine particles and odorous compounds that are attached to them. By landscaping with both a treeline and a row of shrubs, particles at various heights within a plume can be adsorbed. To maximize adsorption, landscape materials with large surface areas are recommended. Trees and shrubs placed around the facility should not impede building ventilation and are often located on the property lines.

> Trees and shrubs act as biofilters for fine particles and odorous compounds . . .

Costs associated with landscaping will vary depending on selected trees and shrubs, and perimeter size. Estimates of a shelterbelt planted around a 3,000-head hog facility using “higher” cost trees ($25 per shrub or tree), calculated out to $0.68 per pig for one year, amortized over 20 years at 5 percent interest, is just $0.09 per pig. These costs include maintenance costs. In addition to acting as a natural filtration system for odors, landscaping has the additional benefits of being aesthetically pleasing to the eye and of

Liquid swine manure in concrete pit covered with Leka rock.

restricting the view of the operation. So, while documented effectiveness on emissions is scarce, the value of creating a facility that is pleasant to the eye cannot be underestimated.

Dietary Manipulation

Feedstuff selection may impact manure dust when excreted or during storage. Studies with pigs and cattle suggest that by adding fat or oil to diets the feces become stickier, reducing dust concentrations in the house. Adding ground, full-fat soybeans to pig diets reduces aerial dust levels. In confinement buildings, dust may be decreased by 30 to 40 percent when full-fat soybeans are included in pig diets instead of soybean meal. Lower dust levels improve the health of pigs and people who work in confinement buildings. However, in order to avoid negative animal performance impacts, dietary energy content should not exceed nutrient recommendations.

Dust and Particulate Control Strategies for Manure Storage Facilities

Following is a summary of practices that can be employed to reduce dust stemming from manure storage facilities. The principle behind these practices is that dust movement will be slowed or prevented.

Impermeable Covers

Covering a manure storage area with an impermeable cover prevents the release of dust and gases into the atmosphere. Polyethylene covers typically range in price from $1.00 to $1.40 per square foot, installed.

Wind damage and snow-load damage present the greatest challenges to implement the extended use of impermeable covers. Damage due to weather effects alters the life of the cover, impacting the capital investment required over time. Many manufacturers list a useful life of 10 years if the facility is constructed to prevent snow accumulation on the cover but do not provide any guarantee against wind damage.

Permeable Covers

Permeable covers, or biocovers, act as biofilters on the top of manure storage areas. Materials often used as covers include straws, cornstalks, peat moss, foam, geotextile fabric, and Leka rock. Permeable biocovers reduce dust by acting as a barrier. Although dust reductions are undocumented, reports of odor reductions of 40 to 50 percent and greater are common when various straw materials are used. An 85 percent reduction in odor has been noted following the use of a floating mat or corrugated materials.

> Permeable biocovers reduce dust by acting as a barrier.

Costs for biocovers vary widely depending on material used and method of application. Straws and cornstalks cost approximately $0.10 per square foot, applied; peat moss and foam cost about $0.26 per square foot, and Leka rock is approximately $2.50 per square foot for a 3-inch layer. Leka rock is a product of

Norway, thereby requiring considerable shipping costs ($5 to $6 per cubic foot). The cost to cover a 1.5-acre earthen storage was $6,000 whereas an above ground tank (0.2 acre) was $500, for the same material.

Cover depth is very important for permeable covers. Most recommendations for straw and stalk covers suggest a minimum of 8-inch depth, preferably 10- to 12-inch depth of coverage on a manure storage surface, whereas Leka rock requires only a 3-inch depth. New covers (except Leka rock) need to be applied at least annually, and one study showed that only 50 percent of the straw cover remained four months after installation. However, an operation in Minnesota employed a ⅛-inch thick geotextile material that cost $0.25 per square foot, plus installation costs. Straw was added on top of the geotextile cover for additional odor control. Management and re-investment costs, and the removal of large, fibrous material during storage cleanout must be considered before selecting this option.

Dust Control Strategies for Open Lots

Dust emissions from open feedlots are controlled primarily by moisture content of the feedlot surface. Dust is the predominant problem at low moisture content. However, because at high moisture content odor can also be a problem, it is impossible to minimize dust and odor by moisture management alone. Researchers have found that when the moisture content of the open lot surface is between 25 and 40 percent, both dust and odor potentials are at manageable levels. To reach the optimum range, open lots must be designed to reduce the ponding of water on the lot as well as the buildup of manure along fence lines and bunk areas.

Dust emissions from open feedlots are controlled primarily by moisture content . . .

Beyond design, maintenance of lots will also help control dust. The key is to keep the lot surface hard, smooth, as dry as possible, and with a firm 1- to 2-inch base of compacted manure above the mineral soil. In flat feedlots or where rainfall is plentiful, an interval of 120 days or more between manure-removal activities will almost certainly lead to lot conditions that generate odor. In Texas, a few modern, large feedlots (capacity greater than 35,000 head) have experimented with continuously harvesting the manure across the yard with two or three tractors with box scrapers, even with cattle present. Lot conditions are excellent, and managers report little to no depression in feed-to-gain performance or increased cattle stress.

Stocking density (number of animals per unit of lot area), or its inverse, animal spacing, may be adjusted to compensate for increases in net evaporative demand (evaporation depth less the effective or retained precipitation), shifting the moisture balance in favor of dust control.

A commercial feedlot in the Texas Panhandle found that decreasing cattle spacing from 150 to 75 square feet per head reduced net PM10 concentrations, at the lot fence line, by about 20 percent. Net PM10 concentrations are the measured particulate matters that are smaller than 10 microns in diameter (PM10), less the background. As daily net evaporation increases, the effectiveness of increased stocking density is likely to decrease. Furthermore, increasing stocking density may induce behavioral problems and reduce overall feed-to-gain performance.

Open lot surface amendments are still under experiment for dust and odor control. Crop residue mulches (waste hay, cotton gin trash) may cushion hoof impact, reduce the shearing that causes dust, and decrease the net evaporative demand by storing additional water and reducing evaporation rates. Resins and petroleum-based products, which have been shown to reduce dust emissions from unpaved roadways significantly, may also be effective. However, the continuous deposition of manure on lot surface suggests that these compounds would need to be reapplied frequently and would therefore be costly.

Solid-set sprinkler systems are an effective but expensive means of dust control in cattle feedlots. Research in California showed that dust concentrations in interior lots increased 850 percent after sprinkler operation had stopped for two days.

Sprinkler systems require site-specific design based on seasonal water balance calculations, but in general, systems should have sufficient capacity to deliver 0.25 inch or more of water per day across the entire yard. Sprinkler patterns should overlap by 50 percent of the diameter of throw, and sprinklers should be located so that their throw does not extend all the way to the feed apron.

If possible, avoid long-term stockpiling of manure.

If possible, avoid long-term stockpiling of manure. Unmanaged stockpiles will eventually exclude oxygen, and even if the stockpiles are not odorous, old, stockpiled manure releases more odor when land applied than manure that is exposed to oxygen. If stockpiling is necessary, minimize stockpile size.

The general approach to dust control consists of
(1) removing dry, loose manure from the lot surface;
(2) manipulating the moisture at the lot surface to achieve optimum moisture content; and
(3) attempting to reduce peak cattle activity during the critical, late afternoon hours, when dust nuisance is most likely to occur.

Conclusions

Employing practices to control dust from livestock facilities can result in less odor and fewer nuisance concerns. A number of practices are available but not all are suited for all operations. Careful consideration and selection will ensure that you obtain the desired results. Regardless of the practice selected, common sense and consideration of neighbors are necessary components of a sound dust control plan.

Resources

For a list of research reports, ISU Extension publications, and links to current news regarding air quality and animal agriculture, please visit the Air Quality and Animal Agriculture Web page at: http://www.extension.iastate.edu/airquality.

PM 1970a *Practices to Reduce Odor from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1970a.pdf

PM 1971a *Practices to Reduce Ammonia Emissions from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1971a.pdf

PM 1972a *Practices to Reduce Hydrogen Sulfide from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1972a.pdf

PM 1973a *Practices to Reduce Dust and Particulates from Livestock Operations* is found on the Web at: http://www.extension.iastate.edu/Publications/PM1973a.pdf

Prepared by Wendy Powers, environmental extension specialist, Department of Animal Science, Iowa State University. Reviewed by David Schmidt, extension engineer, University of Minnesota. Edited by Marisa Corzanego, extension communications intern, Communication Services, Iowa State University Extension. Designed by Jane Lenahan, graphic designer, Instructional Technology Center, Iowa State University.

File: Environmental Quality 4-1

2.3 Bmp Flow Charts

Flow charts for odor, ammonia, hydrogen sulfide, and dust and particulates have been developed as one-page overviews which break the bmp's down by both liquid versus dry manure, and further by housing, storage and application practices. Each bmp has a relative cost and effectiveness associated with it. The costs are represented based on a ranking system of 1 through 3 dollar signs ($=low cost, $$=moderate cost, $$$=high cost). The costs include capital investment plus operations costs. The emission reduction effectiveness is represented as a percentage based on estimated reductions as found in the literature (conservative estimates recognizing that observed reductions may vary from site to site). The flow charts are located at the end of this chapter as Charts 2-1 through 2-4..

2.4 Potential Negative Environmental Impacts

After completion of the fact sheets and flow charts the group compiled a list of potential negative environmental impacts associated with the bmp's (Table 2-1). One concern of interest is that several of the proposed bmp's for the reduction of one pollutant may actually increase the emissions of others (ex: aeration and composting may reduce hydrogen sulfide emissions but may increase ammonia emissions and acidification may reduce ammonia emissions but may increase hydrogen sulfide emissions).

2.5 Bmp Dissemination and Updates

With the completion of a compilation of current acceptable bmp's, the group discussed possible ways to disseminate the information to the producers. The group came up with a list of four suggested methods to distribute the information:

1) Create pamphlets summarizing the bmp's (including web links)
2) Create a display at State and County Fairs
3) Present information at different producer group meetings
4) Develop regional workshops with field days at sites currently utilizing different bmp's

The workgroup also suggested that the DNR conduct periodic literature reviews to stay abreast of new technologies as they develop. However, the group did not discuss how new technologies would be assessed as an acceptable bmp.

2.6 Closing Comments

One thing that is important to remember while reviewing the bmp's is that they will be site specific for each operation. Differences in operation management, structure size and design and location may all play roles in which practice would be best for a specific operation. For example, biofilters are an effective practice to reduce odors from a confined AFO, however, they may not be applicable to an operation that is using natural ventilation without major modification to their air handling system.

Another important thing to be aware of while evaluating the effectiveness of bmp's is that minimal data is currently available on how implementation of multiple practices would reduce emissions of the different pollutants. For example, by implementing both diet manipulation and biofilters the odor reduction may not be a direct additive effect of the two practices working independently.

Much research is still needed and is ongoing in the field of air emission reductions associated with AFOs. However, the findings of this task force demonstrate that current technologies are available to producers to reduce air emissions from livestock operations.

Table 2-1

Potential Negative Environmental Impacts of Bmp's:

Practice	Potential Negative Environmental Impact
Biofilters	Rodents
Landscaping	Ensure non-invasive plants utilized
Solids separation	2 streams of manure to manage
Aeration	Increase ammonia emissions (noted in fact sheet)
Anaerobic Digestion	Must flare off gases
Covers	Peat moss-non renewable, Potential solid waste disposal depending on media chosen
Composting	Potential runoff, ammonia emissions (noted in fact sheet), CO_2 emissions
Manure Additives	Unknown
Injection	Soil compaction
Irrigation	Volatilization (ammonia loss), Runoff potential
Dry Manure	Maintaining dry conditions may increase ammonia loss
Incorporation	Erosion potential
Acidification	Promotes H_2S loss, change in soil pH from continued land application?

Chart 2-1

Flow Chart for Odor Control Practices

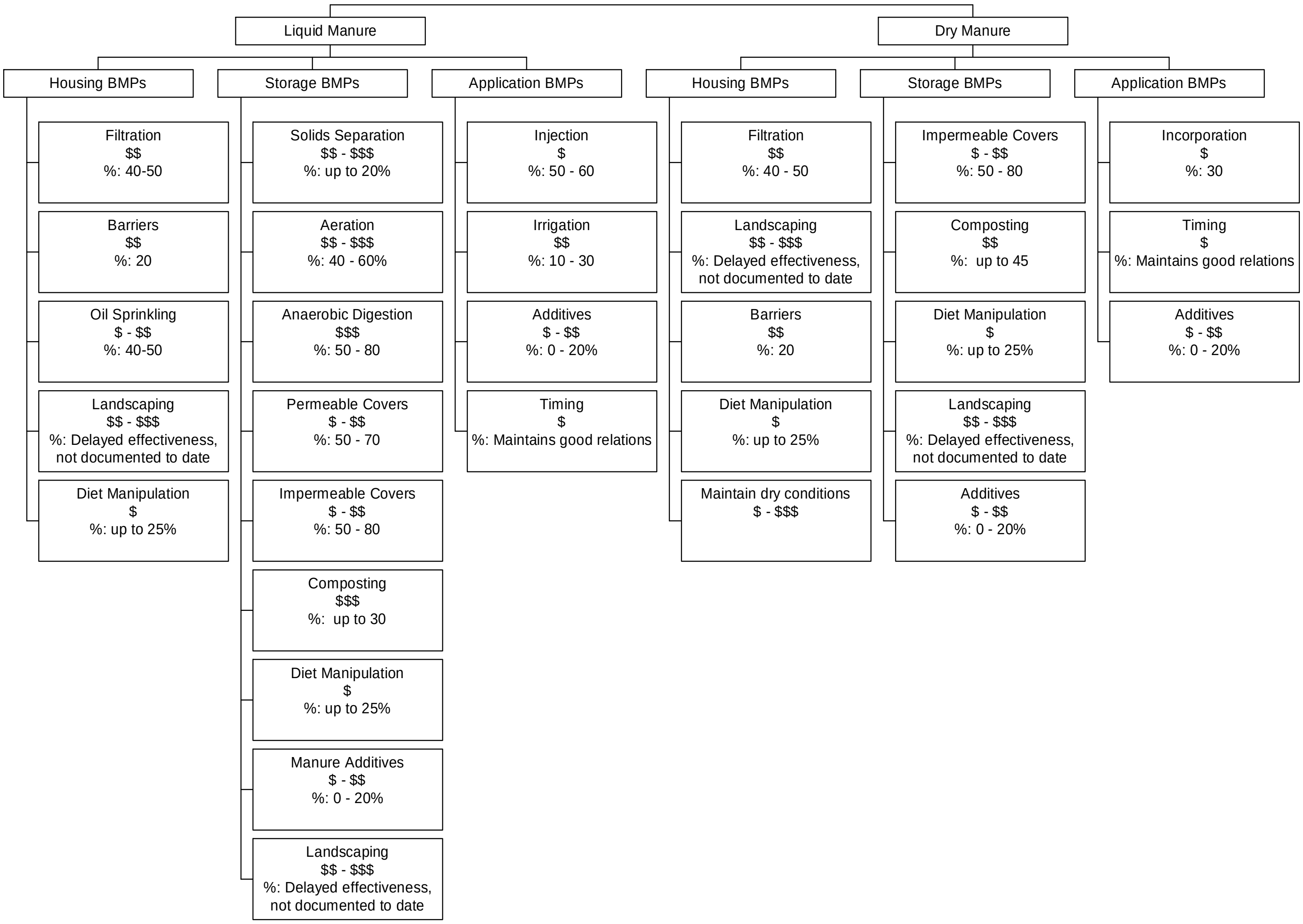


Chart 2-2

Flow Chart for Ammonia Control Practices

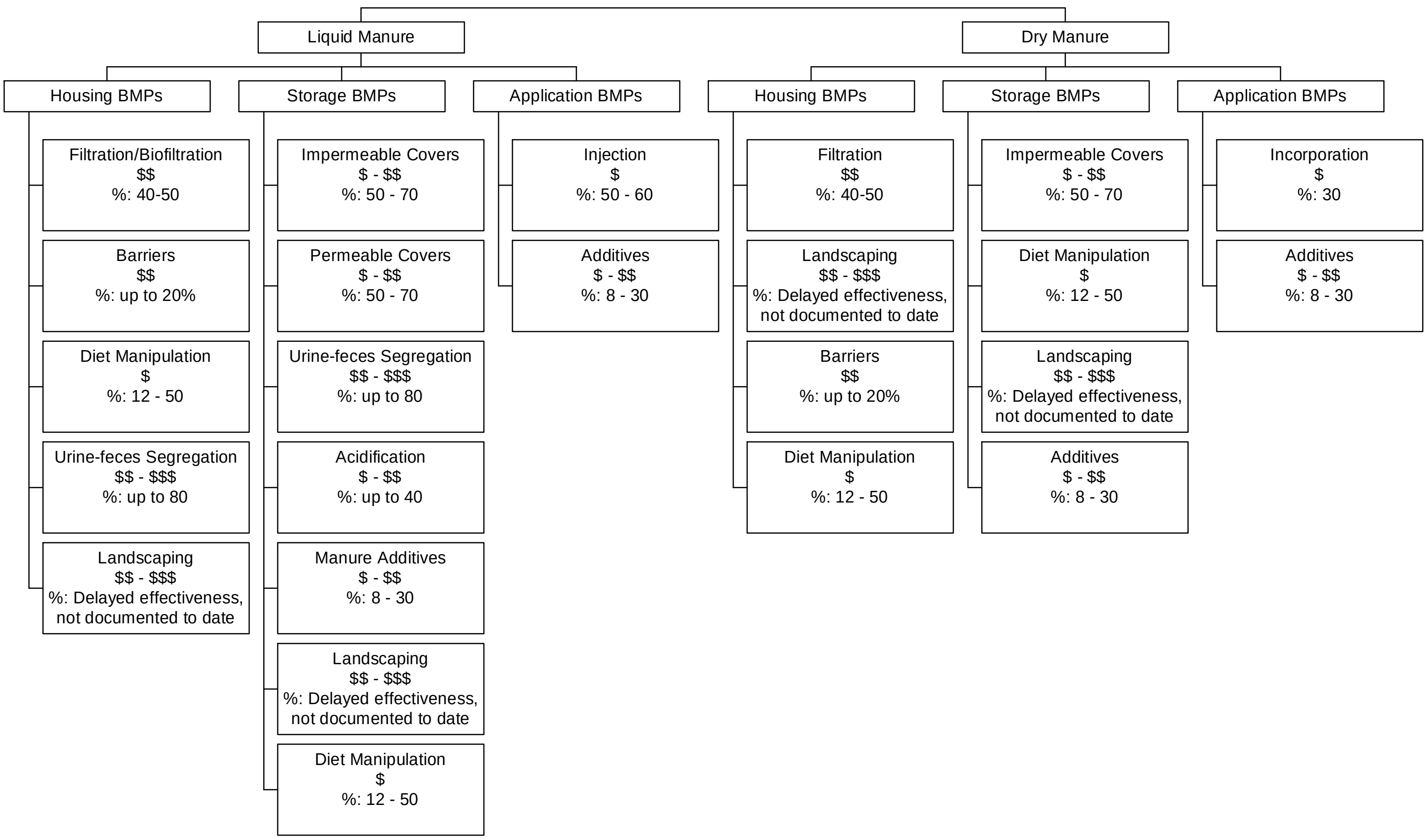


Chart 2-3

Flow Chart for Hydrogen Sulfide Control Practices

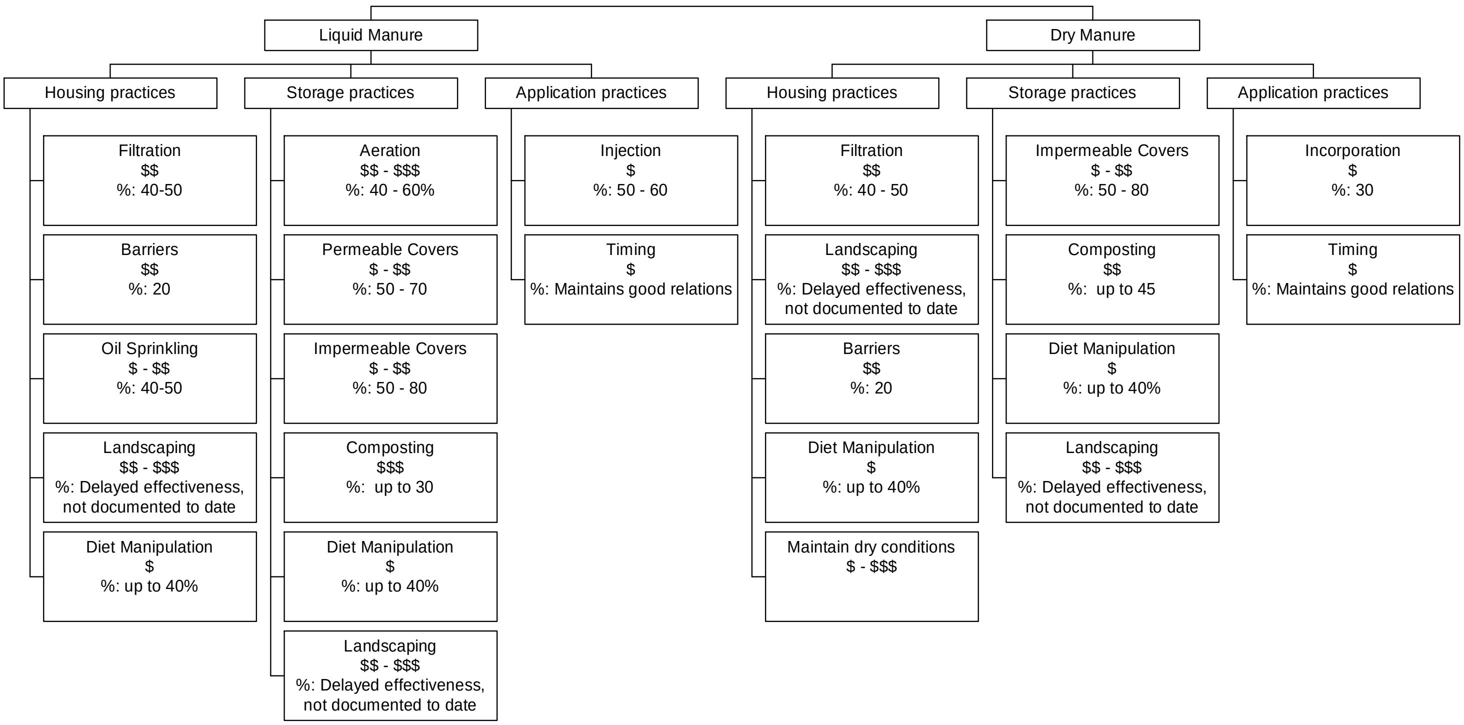
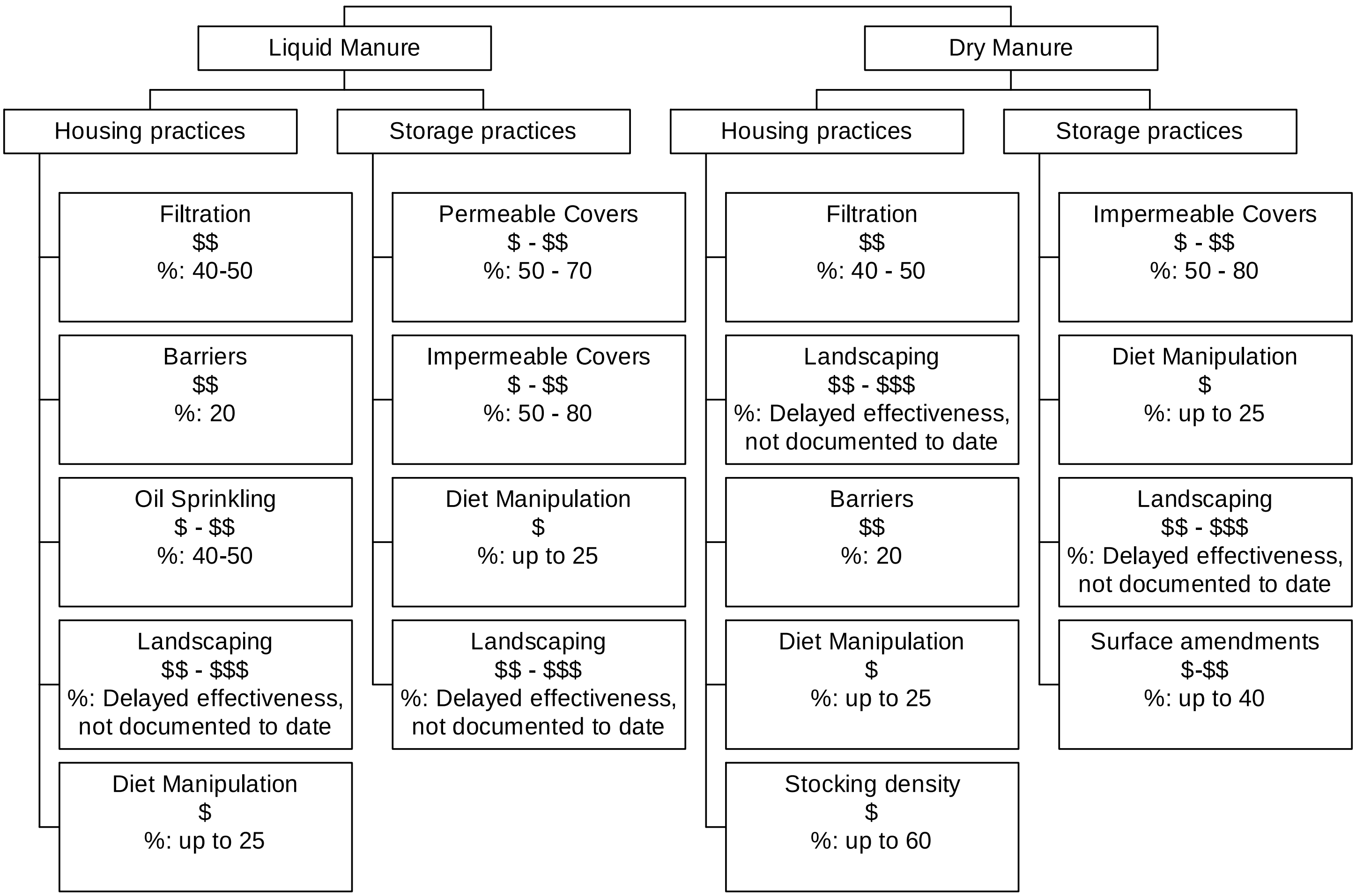


Chart 2-4

Flow Chart for Dust/Particulate Control Practices



3.0 Air Emissions Characterization

3.1 Introduction

The Air Emissions Characterization workgroup performed a review of current literature on emission factors and techniques for the estimation of hydrogen sulfide, ammonia, odor, and particulate matter emissions from AFOs. Emission factor data for each of these pollutants is summarized in Tables 3-1 through 3-4 by pollutant. Inclusion of an emission factor in the tables does not mean that the workgroup is advocating the use of that emissions factor. The intent of the workgroup was to provide enough information for users to choose the best emission factor for a specific situation.

3.2 Purpose

The charge of the Air Emissions Characterization workgroup was to identify emission factors currently available that can be used to estimate emissions of hydrogen sulfide, ammonia, and odor emissions from AFOs.

In addition, particulate matter with an aerodynamic diameter less than or equal to 10 microns (PM_{10}) was studied by the workgroup because fine particulate matter can be a carrier for odor. Additionally, PM_{10} can be easily inhaled by humans, causing adverse health affects.

3.3 Methodology

The workgroup started with seven questions provided by the DNR and added an eighth question of their own:

1. What are the sources of pollutants at an AFO?
2. What source/s contribute the most to the atmosphere?
3. What emission factors are available that accurately characterize emissions from sources at AFOs, and are they applicable to Iowa?
4. What process models are available to characterize emissions from AFOs?
5. What animal types are sources of pollutants and how do they vary?
6. What characteristics of building structures impact the emission of pollutants?
7. What characteristics of waste storage structures impact the emissions of pollutants?
8. What land application types are sources of pollutants and how do they vary?

After a general discussion of these questions, the workgroup decided to focus on emission factors. The workgroup chose not to address the fourth question regarding process models because many process models are currently still in development and because these models were beyond the technical expertise of the majority of the workgroup members.

The workgroup then conducted a literature review of available emission factors. When possible, the workgroup tired to focus on emission factors that had been published in studies included in the “Iowa Concentrated Animal Feeding Operations Air Quality Study” final report of 2002 or published after it was released. The review focused on four pollutants: hydrogen sulfide, ammonia, odor, and particulate matter. Each pollutant was then assigned to either a single individual or small subgroup, and a standardized emission factor table was designed for group use. A draft emission factor summary for each pollutant was provided by each subgroup to the workgroup for review and comment before being finalized.

3.4 Emission Factor Background

There are several ways to estimate emissions from a process. The preferred methods are continuous emissions monitoring, which provides constant measurement of a pollutant, and emissions testing, which provides an exact measurement of a pollutant during a set time period, because these methods are the most representative of the tested source's emissions. However, test data from individual sources are not always available and, even if they are available, they may not reflect the variability of actual emissions over time. Thus, emission factors are frequently the best or only method available for estimating emissions, in spite of their limitations.[1]

Emission factors represent industry averages and show the relationship between emissions and a measure of production. Not all emission factors are created equal. Emission factors that are derived from a large amount of industry-wide emissions testing are given high rankings, while emission factors derived from a single test are given the lowest ranking.

When reviewing the AFO emission factors provided in Tables 3-1 through 3-4, it is important to note that the AFO emissions factors provided generally do not account for climate and geography, diurnal and seasonal emission patterns, feeding practices, animal life stage, individual animal management practices, or pH. The workgroup has added notes, where possible, to indicate the conditions such as type of housing unit, type of animal, season, etc. affecting the emission factor.

Hydrogen sulfide data in Table 3-1 were compiled from sources identified from searches of the National Library of Medicine (Pub Med), through targeted Web searches, and from a number of reports that summarize published literature. The original sources of these data list values in various forms and units. In some cases, details regarding the nature of the livestock facility studied are limited. Thus, in order to determine hydrogen sulfide emission factors in grams per day per animal unit (g/day•AU) assumptions were sometimes made.

Emission factors for ammonia are summarized in Table 3-2. The emission factors are from several studies and include average emission factors calculated by the Environmental Protection Agency (EPA) in January 2004 (shaded in the table).

Emission factors for odor are summarized in Table 3-3. It is important to remember that the definitions of odor units (OUs) and detection thresholds (DTs) vary according to which odor method was used during the study. The odor methods used are listed at the end of Table 3-3. In general, odor units are defined as the volume of diluted (non-odorous) air divided by the volume of odorous sample air at either detection or recognition. Odor units are dimensionless numbers.

Emission factors for PM_{10} are summarized in Table 3-4.

[1] Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume 1: Stationary Point and Area Sources, Jan. 1995, p. 1.

3.5 How to Estimate Emissions Using an Emission Factor

In general, emissions can be estimated using emission factors according to the following equation:

Emissions = Production Rate x Emission Factor x ((1 – % Control Efficiency)/100)

The workgroup did not address control efficiency in their work for this report. Examples of how to use emission factors provided in this report are as follows:

Example #1
Estimate hydrogen sulfide (H_2S) emissions from 1,000 cattle in a feedlot with passive ventilation.

Choose an emission factor that fits this situation from those listed Table 3-1 such as 0.888 g/day · AU. The study from which the emission factor was taken considers 1 feeder cow to equal 1 animal unit. Assume 1 pound equals 454 grams.

$$1{,}000 \text{ feeder cattle} \times \frac{1 \text{ AU}}{1 \text{ feeder cattle}} \times \frac{0.888 \text{ g H2S}}{\text{day} \cdot \text{AU}} \times \frac{\text{lb. H2S}}{454 \text{ g H2S}} = \frac{1.96 \text{ lbs. } H_2S}{\text{day}}$$

Example #2
Estimate ammonia (NH_3) emissions from poultry CAFO, with a size of approximately 20,000 broilers.

Choose an emission factor that fits this situation from those listed in Table 3-2 such as 0.22 lb/year/head. Assume 1 broiler = 1 head.

$$20{,}000 \text{ head} \times \frac{0.22 \text{ lb Ammonia}}{\text{year/head}} = \frac{4{,}400 \text{ lbs. Ammonia}}{\text{year}} \times \frac{\text{year}}{365 \text{ days}} = \frac{12 \text{ lbs. } NH_3}{\text{day}}$$

3.6 Emission Factor Use

Emission factors can be used in emissions inventories and atmospheric dispersion modeling analyses. Inventories provide a method of tracking emission trends over time. Inventories are created by applying emission factors to a set of activity data or production data for a certain time period.

Atmospheric dispersion models are routinely used to estimate the ground level concentration of pollutants emitted into the atmosphere. These models use mathematical representations of physical and chemical atmospheric processes in combination with characterization of air pollutant emissions to simulate the transport and diffusion of pollutants from a source of release. Emission factors are used to estimate the rate that a substance is released into the atmosphere from a source. The Dispersion Modeling workgroup recommends application of the American Meteorological Society / Environmental Protection Agency Regulatory Model (AERMOD)[2] for estimation of odor, hydrogen sulfide and ammonia concentrations from AFOs. To read more about their recommendations, please refer to Chapter 4.0 of this report.

[2] http://www.epa.gov/scram001/7thconf/aermod/aermodug.pdf

3.7 Conclusion

The emission factors in Tables 3-1 through 3-4 are reported by the workgroup with the intent of providing the public with one centralized location to find emission factors that may be used to estimate emissions from AFOs. Users should consider the animal type, housing type, any geographic or seasonal information, and whether the data was peer-reviewed or not. When evaluating emission factors from other countries, users should also consider how the feeding and housing practices in that country differ from those in Iowa. Finally, users should note that using an emission factor to calculate emissions results in an estimation of pollution over a certain amount of time (hour, day, year). It will not provide the concentration of a pollutant in the ambient air.

Table 3-1A: Hydrogen Sulfide Emission Factors - Housing

Livestock	Housing System	Operation Type	Ventilation System	H_2S Emissions	H_2S Emission Factors (lb/day.place)	H_2S Emission Factors (g/day.AU)	Comments	Ref
Swine	CAFO	Finisher	Passive	7.7 ug/sec.m^2	0.00109	1.24	Assumes 8 ft^2/pig	1
Swine	CAFO	Finisher	Passive		0.0015	1.70	June-Sept, deep pitted	2
Swine	CAFO	Finisher	Passive		0.00033	0.375	1000 head, mean rate	3
Swine	CAFO	Finisher	Passive		0.16	182	Deep pitted approx’n based on manure storage facility (Stirred slurry?)	4
Swine	CAFO	Finisher	Mechanical	7.1 ug/sec.m^2	0.00101	1.15	Assumes 8 ft^2/pig	1
Swine	CAFO	Finisher	Mechanical	610 mg/day. m^2		6.71	Cold weather, Building 3B, 1000 head, deep pit	6
Swine	CAFO	Finisher	Mechanical	610 mg/day. m^2		32.3	Warm weather, Building 3B, 1000 head, deep pit	6
Swine	CAFO	Finisher	Mechanical	910 mg/day. m^2		5.89	Cold weather, Building 4B, 1000 head, deep pit	6
Swine	CAFO	Finisher	Mechanical	910 mg/day. m^2		35.9	Warm weather, Building 4B, 1000 head, deep pit	6
Swine	CAFO	Gestation	Mechanical	0.7 ug/sec.m^2	0.00010	0.114	Assumes 8 ft^2/pig	1
Swine	CAFO	Farrowing	Mechanical	5.5 ug/sec.m^2	0.00078	0.888	Assumes 8 ft^2/pig	1
Swine	CAFO	Nursery	Mechanical	45.7 ug/sec.m^2	0.00647	7.34	Assumes 8 ft^2/pig	1
Chickens	CAFO	Broilers	Mechanical	0.2 ug/sec.m^2	0.00000354	0.0587	Assumes 1 ft^2/broiler	1
Cattle	Feedlot		Passive	0.990 kg/yr.m^2	0.00069	0.115	Assumes 40ft^2/cattle	7
Dairy	Freestall		Passive	0.4 ug/sec.m^2	0.00028	0.0332	Assumes 40ft^2/cow	1

Table 3-1B: Hydrogen Sulfide Emission Factors – Manure Storage

Livestock	Housing System	Operation Type	Manure System	H_2S Emission Flux	H_2S Emission Rate (g/system.hr)	H_2S Emission Factors (g/day.AU)	Comments	Ref
Swine	CAFO	Manure storage lagoon	Open lagoon	0.73 ng/sec.cm^2 0.82 ng/sec.cm^2 2.11 ng/sec.cm^2		4.55 Aug. 5.12 Sept. 13.2 Oct.	5400 finisher pigs/yr 2 cycles/yr Lagoon 7800 m^2	9
Swine	CAFO	Manure storage lagoon	Open lagoon A	9.1 +/- 1.6 ug/sec.m^2 (mean +/- 95% CI)		2.80	Apr-Jul 2000, 6 visits 8636 AU 30,735 m^2	5
Swine	CAFO	Manure storage lagoon	Open lagoon B	2.3 +/- 3.2 ug/sec.m^2 (mean +/- 95% CI)		1.95	May-Jul 2000, 6 visits 1252 AU 12,310 m^2	5
Swine	CAFO	Feeder to finisher, mechanically ventilated	Deep pit, under-slat, short term or long term	0.37 ng/sec.cm^2	5.9	(0.052)	13,680 pigs/yr	8
Swine	CAFO	Farrow to finisher, Manure Storage	Earthen concrete, or metal-lined storage basins	1.10 ng/sec.cm^2	12.5	(0.183)	8,200 pigs/yr	8
Swine	CAFO	Feeder to finisher, Manure Storage	Lagoon, without anoxic photosynthetic blooms	0.32 ng/sec. cm^2	22.7	(0.192)	14,170 pigs/yr	8
Swine	CAFO	Farrow to feeder, Manure Storage	Lagoon, with anoxic photosynthetic blooms	0.24 ng/sec. cm^2	16.9	(0.110)	18,500 pigs/yr	8

Animal Units (AU)
Tables 3-1A and 3-1B assume 2.5 swine > 25 kg = 1 AU, 1 feeder cattle = 1 AU. 1 dairy cow = 1.4 AU, 100 Broilers = 1 AU

References for Tables 3-1A and 3-1B

1. Zhu J, Jacobson LD, Nicolai R, Schmidt D. 1998. Unpublished data, University of Minnesota, Dept. of Biosystems and Agricultural Engineering.
2. Ni J, Lim TT, Heber AJ, et al. 1998. Ammonia emission from a large mechanically ventilated swine building during warm weather, St. Joseph, MI. ASAE Paper No. 98-4051.
3. Heber AJ, Duggirala RK, Ni J. et al. 1997. Manure treatment to reduce gas emissions from large swine houses. In Voermans JAM, Monteny G, eds. Procs. Intern. Symp. On Ammonia and Odor Control from Animal Production Facilities, Vinkeloord, The Netherlands, Rosmalen, The Netherlands, NVTL 2, pg 449-457.
4. Hobbs PJ, Misselbrook TH, Cumby TR. 1999. Production of emission of odors and gases from ageing pig waste J Ag Engr Research 72(3):291-198.
5. Lim TT, Heber AJ, Ni J-Q, Sutton AL, Shao P. 2003. Odor and gas release from anaerobic treatment lagoons for swine manure. J Environ Qual 32:406-416.
6. Ni J, Heber AJ, Lim TT, et al. 1999. Continuous measurement of hydrogen sulfide emission from two large swine finishing buildings. ASAE Paper No. 99-4132.
7. Baek, B, Koziel J, Kiehl L, Spinhirne J, Cole N. 2003. Integrated management regimens that minimize environmental impact of livestock manure. Proc ASAE, 2003.
8. Zahn JA, Hatfield JL, Laird DA, Hart TT, Do YS, DiSpirito AA. 2001. Functional classification of swine manure management systems based on effluent and gas emission characteristics. J Environ Qual 30:635-647.
9. Zahn JA, Tung AE, Roberts BA, Hatfield JL. 2001. Abatement of ammonia and hydrogen sulfide emissions from a swine lagoon using a polymer biocover. J Air & Waste Manage Assoc 51:562-573.

Table 3-2: Ammonia Emission Factors

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Poultry	Dry Layer Houses	-		87	lb/NH3/AU-yr	0.87				Valli et al., 1991	1
		-		41.6 - 74.8	% of N	0.90				Yang et al., 2000	1
		-		AVERAGE		0.89				Calculated by EPA	1
Poultry	Wet Layer Houses	-		110	g/hen/yr	0.24				Kroodsma et al., 1988	1
		-		83	g/hen/yr	0.18				Hartung and Phillips, 1994	1
		-		38.8	kg/500 kg L W	0.31				Hartung and Phillips, 1994	1
		-		AVERAGE		0.25				Calculated by EPA	1
Poultry	Broiler Houses	-		0.065	kg/animal/yr	0.14				Asman, 1992	1
		-		18.5	mg/hr/broilers housed in litter					Groot Koerkamp et al., 1998	1
		-		8.9	mg/hr/broilers housed in litter					Groot Koerkamp et al., 1998	1
		-		19.8	mg/hr/broilers housed in litter					Groot Koerkamp et al., 1998	1
		-		11.2	mg/hr/broilers housed in litter					Groot Koerkamp et al., 1998	1
		-		21.9	g/animal/fattening period					Kroodsma et al. 1998	1
		-		0.1	kg/broiler/yr	0.22				Tamminga, 1992	1
		-		0.15	kg/animal/yr	0.33				Van Der Hoek, 1998	1
		-		AVERAGE		0.22				Calculated by EPA	1
Poultry	Dry Layer	Manure Land Application		7	% of N applied					Lockyer and Pain, 1989	1
	Wet Layer			41.5	% of N applied					Lockyer and Pain, 1989	1
	Broiler			25.1	% of N applied					Cabera et al., 1994	1
Poultry	Houses	-		36.0	% NH3-N loss	0.5				Bowman et al., 1997	3, 4, 5
Poultry	Caged Layers	Winter	VA	8	g NH3/AU-h			192		Wathes et al., 1997	2
		Summer	VA	12.5	g NH3/AU-h			300		Wathes et al., 1997	2

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Poultry	Broilers	Winter	VA	9	g NH3/AU-h			216		Wathes et al., 1997	2
		Summer	VA	9	g NH3/AU-h			216		Wathes et al., 1997	2
		On litter	VA	4 - 20	ug NH3/m2-s			7 -33		Zhu et al., 2000	2
		On litter	VA	18.6	kg NH3/AU-yr			51		Demmers et al., 1999	2
		First flock on new bedding	ST	149 - 314	mg NH3-N/m2-h			4.3 - 9.1		Brewer and Costello, 1999	2
		After four flocks on bedding	ST	208 - 271	mg NH3/m2-h			6.0 - 7.9		Brewer and Costello, 1999	2
		-		0.28	kg-NH3/animal-yr					Battye, et al., 2003	3
Poultry	Laying Hens	On litter	VA	7,392 - 10,892	mg NH3/AU-h			177 - 261		Groot Kooerkamp et al., 1998	2
		Cages	VA	602 - 9,316	mg NH3/AU-h			14 - 224		Groot Kooerkamp et al., 1998	2
		-		0.37	kg-NH3/animal-yr					Battye, et al., 2003	3
Poultry	Turkey Houses	-		0.429 - 0.639	kg/animal/yr	1.18				Asman, 1992	1
		-		0.48	kg/animal/yr	1.06				Van Der Hoek, 1998	1
		-		AVERAGE		1.12				Calculated by EPA	1
Swine	Houses	Lagoon Systems (includes flush houses, pit recharges & pull plug systems)		229.1	mg/head/hr	4.0				Andersson, M., 1998	1
				3.1	kg/animal/yr	6.8				Oosthoek et al., 1991	1
				3	kg/head/yr	6.6				Oosthoek et al., 1991	1
				3.7	kg/finish pig/yr	8.2				Harris and Thompson, 1998	1
				13	lb/1000 pigs/day	4.3				Heber, 1997	1
				AVERAGE		6.0				Calculated by EPA	1
Swine	Houses	Deep-Pit Systems		3.18	kg/fattening pig/yr	7.0				Asman, 1992	1
				10.0 - 12.0	g NH3/animal/day	8.1				Hoeskma et al., 1993	1
				8.0 - 9.0	g NH3/animal/day	6.2				Hoeskma et al., 1993	1
				255	g/hour/858 pigs	5.2				Ni et al., 2000	1
				186	g/hour/870 pigs	3.8				Ni et al., 2000	1
				145	g NH3/500 kg L W-day	12.5				Ni et al., 2000	1
				3	kg/animal/yr	6.6				Oosthoek, et al., 1988	1
				34.9 - 44.6	lb/day/2000 finishing hogs	6.6				Secrest, 1999	1
				13	g/head/day	9.5				USDA, 2000	1
				AVERAGE		7.3				Calculated by EPA	1

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Swine	Lagoons	-		2.2	kg N/yr/head	5.9				Aneja et al., 2000	1
		-		64.7	% of excreted N	17.6				Fulhage, 1998	1
		-		6.53	kg NH3/yr/head	14.4				Koelliker and Miner, 1971	1
		-		77.2	% of excreted N	21.0				Fullhage, 1998	1
		-		8,210	kg/yr/500 AU	14.5				Martin, 2000	1
		-		5,602	kg/yr/500 AU	9.9				Martin, 2000	1
		-		AVERAGE		13.9				Calculated by EPA	1
Swine	Manure Land	Liquid (>2,000 head)		20	% N lost					Calculated by EPA	1
		Liquid (<2,000 head)		23	% N lost					Calculated by EPA	1
		Solid (>2,000 head)		19	% N lost					Calculated by EPA	1
		Solid (<2,000 head)		17	% N lost					Calculated by EPA	1
Pigs	Finishing	-	VA	5,700 - 5,900	mg NH3/pig-day			42 - 43		Aarnink et al., 1995	2
		-	VA	46.9	kg NH3-N/AU-yr			160		Demmers et al., 1999	2
		-	VA	0.9 - 3.2	kg NH3-N/day					Burton and Beauchamp, 1986	2
		on bedding	VA	1,429 - 3,751	mg NH3/AU-h			34 - 90		Groot Kooerkamp et al., 1998	2
		on slats	VA	2,076 - 2,592	mg NH3/AU-h			50-62		Groot Kooerkamp et al., 1998	2
		Lagoon	ST	18	ng NH3/cm2-s				16	Zahn et al., 2001	2
		-	ST	4.35	g NH3/m2-day				4.4	Hobbs et al., 1999	2
		Uncovered, no crust	ST	4.3	g NH3-N/m2-day				5.2	Sommer et al., 1993	2
		Uncovered, with crust	ST	0.5 - 1.5	g NH3-N/m2-day				0.6 - 1.8	Sommer et al., 1993	2
		Uncovered, with straw	ST	0.2 - 1.0	g NH3-N/m2-day				0.25 - 1.2	Sommer et al., 1993	2
		Capped with lid	ST	0 - 0.3	g NH3-N/m2-day				0 - 0.36	Sommer et al., 1993	2
		Deep-pit or pull-plug	VA	66	ng NH3/cm2-s			311	57	Zahn et al., 2001	2
		Earthen, concrete, or steel-lined	ST	167	ng NH3/cm2-s				144	Zahn et al., 2001	2
		Non-phototrophic lagoons	ST	109	ng NH3/cm2-s				94	Zahn et al., 2001	2
		Phototrophic lagoons	ST	89	ng NH3/cm2-s				77	Zahn et al., 2001	2
		Mechanically ventilated	VA	20 - 55	ug NH3/m2-s			10 - 26		Zhu et al., 2000	2
		Naturally ventilated, pit fans	VA	60 - 170	ug NH3/m2-s			28 - 80		Zhu et al., 2000	2
		Slurry removed weekly	VA	11	kg NH3/AU-yr			30		Osada et al., 1998	2
		Deep-pit manure storage	VA	11.8	kg NH3/AU-yr			32		Osada et al., 1998	2

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Swine	Houses	-		36.0	% NH3-N loss	11				Bowman et al., 1997	3, 4, 5
Pigs	Nursery	-	VA	700 - 1,200	mg NH3/pig-day			19 - 33		Aarnink et al., 1995	2
		Mechanically ventilated	VA	20 - 140	ug NH3/m2-s			23 - 160		Zhu et al., 2000	2
		-	VA	649 - 1,526	mg NH3/AU-h			16 - 37		Groot Kooerkamp et al., 1998	2
Pigs	Finishing	Nursery-to-finishing	VA	70 - 210	g NH3/h			66		Hinz and Linke, 1998	2
Pigs	Gestation	Mechanically ventilated	VA	5	ug NH3/m2-s			2.2		Zhu et al., 2000	2
Pigs	Sows	on bedding	VA	744 - 3,248	mg NH3/AU-h			18 - 78		Groot Kooerkamp et al., 1998	2
		on slats	VA	1,049 - 1,701	mg NH3/AU-h			25 - 41		Groot Kooerkamp et al., 1998	2
Pigs	Farrowing	Mechanically ventilated	VA	20 - 55	ug NH3/m2-s			15 - 42		Zhu et al., 2000	2
Pigs	-	Surface applied, urine only	LA	700	g NH3/hectare-h				70	Svensson, 1994	2
Pigs	-	Surface applied + immediate cover, urine only	LA	120	g NH3/hectare-h				12	Svensson, 1994	2
Dairy	Scrape Barn	-		8.9	kg/500 kg/yr	23.7				Demmers et al., 2001	1
		-		7 - 13	g/LU/day	9.7				Jungbluth, 1997	1
		-		8.3	g/N/cow/day	8.1				Misselbrook et al., 1998	1
		-		14.5	kg/animal/yr	32.0				Van Der Hoek, 1998	1
		-		AVERAGE		18.5				Calculated by EPA	1
Dairy	Dry lots	-		8.3	g N/cow/day	8.1				Misselbrook et al., 1998	1
		-		8	kg/cow/yr	17.6				USDA, 2000	1
		-		30	lb/head/yr	30.0				USDA, 2000	1
		-		AVERAGE		18.58				Calculated by EPA	1
Dairy	-	-		28	kg-NH3/animal-yr					Battye et al., 2003	3
	Stable*	-		36	% NH3-N loss		50			Bowman et al., 1997	1, 3, 4, 5
	Meadow	-		8	% NH3-N loss		30			Bowman et al., 1997	3, 4, 5
	Total	-		25.5	% NH3-N loss		80			Bowman et al., 1997	3, 4, 5

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Dairy	Manure Storage Tanks	-		6.6	% of N					Safely, 1980	1
Dairy	Solid Storage	-		20 - 40	% N lost					Sutton et al., 2001	1
Dairy	-	On bedding	VA	260 - 890	mg NH3/AU-h			6.2 - 21.4		Groot Kooerkamp et al., 1998	2
Dairy	Free-stall	-	VA	843 - 1,769	mg NH3/AU-h			20 - 42.5		Groot Kooerkamp et al., 1998	2
		Manure slatted floor	ST	400	mg NH3/m2-h				9.6	Kroodsma et al., 1993	2
		Scraped slatted floor	ST	380	mg NH3/m2-h				9.1	Kroodsma et al., 1993	2
		Unstirred slurry below slats	ST	320	mg NH3/m2-h				7.7	Kroodsma et al., 1993	2
		Stirred slurry below slats	ST	290	mg NH3/m2-h				7	Kroodsma et al., 1993	2
		Manure solid floor	ST	670	mg NH3/m2-h			16		Kroodsma et al., 1993	2
		Scraped solid floor	ST	620	mg NH3/m2-h			15		Kroodsma et al., 1993	2
		Flushed solid floor	ST	210	mg NH3/m2-h			5		Kroodsma et al., 1993	2
		-	ST	4	ug NH3/m2-s			0.35		Zhu et al., 2000	2
Dairy	Manure Land Application	Liquid (>200 head)		20	% N lost					Calculated by EPA	1
		Liquid (100 - 200 head)		22	% N lost					Calculated by EPA	1
		Liquid (<100 head)		24	% N lost					Calculated by EPA	1
		Solid (>200 head)		17	% N lost					Calculated by EPA	1
		Solid (100 - 200 head)		18	% N lost					Calculated by EPA	1
		Solid (<100 head)		19	% N lost					Calculated by EPA	1
Cattle	Dry lots	-		35 - 50	lb/day/1000 head	15.5				Grelinger, 1997	1
		-		0.76 - 2.82	g N/head/hour	42.0				Hutchinson et al., 1982	1
		-		18	lb/head/yr	18.0				USDA, 2000	1
		-		AVERAGE		25.2				Calculated by EPA	
Nondairy Cattle	Stable*	-		36	% NH3-N loss		15			Bowman et al., 1997	1, 3, 4, 5
	Meadow	-		8	% NH3-N loss		30			Bowman et al., 1997	3, 4, 5
	Total	-		17.3	% NH3-N loss		45			Bowman et al., 1997	3, 4, 5

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Beef and heifers	Liquid Manure	Land Application		20	% N lost					Calculated by EPA	1
	Solid Manure	Land Application		17	% N lost					Calculated by EPA	1
	Storage Pond	-		20	% N lost					Calculated by EPA	1
Beef	-	-		10.2	kg-NH3/animal-yr					Battye et al., 2003	3
	-	On bedding	VA	431 - 478	mg NH3/AU-h			10.3 - 11.5		Groot Kooerkamp et al., 1998	2
	-	On slats	VA	371 - 900	mg NH3/AU-h			9 - 21.6		Groot Kooerkamp et al., 1998	2
	-	On chopped straw	ST	547	mg NH3/m2-h				13	Jeppsson, 1999	2
	-	On unchopped straw	ST	747	mg NH3/m2-h				18	Jeppsson, 1999	2
	-	On chopped straw + peat	ST	319	mg NH3/m2-h				8	Jeppsson, 1999	2
	-	Uncovered, no crust	ST	4.5	g NH3-N/m2-day			5.5		Sommer et al., 1993	2
	-	Uncovered, with crust	ST	1.3	g NH3-N/m2-day			1.6		Sommer et al., 1993	2
	-	Capped with lid	ST	0.2 - 0.4	g NH3-N/m2-day			0.25 - 0.5		Sommer et al., 1993	2
Calves	-	On bedding	VA	315 - 1,037	mg NH3/AU-h			7.6 - 25		Groot Kooerkamp et al., 1998	2
	-	On slats	VA	1,148 - 1,797	mg NH3/AU-h			28 - 43		Groot Kooerkamp et al., 1998	2
Sheep	All Types	-				7.43				Calculated by EPA	1
	-	-		1.34	kg-NH3/animal-yr					Battye, et al., 2003	3
	Stable*	-		28	% NH3-N loss		1			Bowman et al., 1997	3, 4, 5
	Meadow	-		4	% NH3-N loss		9			Bowman et al., 1997	3, 4, 5
	Total	-		6.4	% NH3-N loss		10			Bowman et al., 1997	3, 4, 5
Goats	All Types	-				14.1				Calculated by EPA	1
	Stable*	-		28	% NH3-N loss		1			Bowman et al., 1997	3, 4, 5
	Meadow	-		4	% NH3-N loss		8			Bowman et al., 1997	3, 4, 5
	Total	-		6.4	% NH3-N loss		9			Bowman et al., 1997	3, 4, 5
Horses	All Types	-				26.9				Calculated by EPA	1
	-			8.0	kg-NH3/animal-yr					Battye, et al., 2003	3

* Emissions from stables include those from animal waste stored outside the stable and from spreading of animal waste.

Abbreviations Used in Table 3-2

AU = Animal Unit, LW = Live Weight, VA = Ventilated Area, ST = Storage, LA = Land Application

Codes for "Studies Included In" in Table 3-2

1. National Emission Inventory - Ammonia Emissions from Animal Husbandry Operations, Draft Report. EPA, January 2004.
2. Iowa Concentrated Animal Feeding Operations Air Quality Study. Iowa State University and The University of Iowa Study Group, February 2002.
3. Research and Development of Ammonia Emission Inventories for the Central States Regional Air Planning Association. Coe, Dana L., and Stephen B. Reid, 2003.
4. Scenarios of Animal Waste Productions and Fertilizer Use and Associated Ammonia Emission for the Developing Countries. Bouwman, A.F. and K. W. Van Der Hoek, 1997.
5. CMU Ammonia Model version 3.0. Davidson, Cliff et al, 2003. http://www.cmu.edu/ammonia

References for Table 3-2

Author(s)	Year	Article/Study
Aarink, AJA, A Keen, JHM Metz, L. Speelman, MWA Verstegen.	1995	Ammonia Emission Patterns During the Growing Periods of Pigs Housed on Partially Slatted Floors. J. Agric. Engng. Res, 62:105-116.
Andersson, M.,	1998	Reducing Ammonia Emissions by Cooling of Manure in Manure Culverts. Nutrient Cycling in Agroecosystems, 51(1): 73-79.
Aneja et al.	2000	Characterization of Atmospheric Ammonia Emissions from Swine Waste Storage and Treatment Lagoons, J. Geophys. Res. – Atmos, 105 (D9), 11535-11545.
Asman, W.A.H.	1992	Ammonia Emission in Europe: Updated Emission and Emission Variations, National Institute of Public Health and Environmental Protections, Report 228471008, Bilthoven, Netherlands
Battye et al.	2003	Evaluation and Improvement of Ammonia Emissions Inventories. Atmospheric Environment 37 (2003) 3873-3883.
Bouwman, et al.	1997	A Global High-Resolution Emission Inventory for Ammonia, Global Biochemical Cycles, 11:4, 561-587.
Bowman, A.F. and K.W. Van der Hoek	1997	Scenarios of Animal Waste Production and Fertilizer Use and Associated Ammonia Emission For the Developing Countries. Atmospheric Environment Vol. 31, No. 24, 4095-4102.
Brewer, SK, TA Costello	1999	In Situ Measurement of Ammonia Volatilization from Broiler Litter Using and Enclosed Air Chamber. Transactions of the ASAE, 42(5): 1415-1422.
Burton, DL and EG Beauchamp	1986	Nitrogen Losses from Swine Housings. Agricultural Wastes, 15(59-74).
Cabera, M.L., S.C. Chiang, O.C. Merka, O.C. Pancorbo, and S.C. Thompson	1994	Pelletizing and Soil Water Effects on Gaseous emission from Surface-Applied Poultry Litter. Soil Science Society of America Journal 58, 807-811.
Demmers et al.	1999	Ammonia Emissions from Two Mechanically Ventilated UK Livestock Buildings. Atmospheric Environment, 33: 217-227.

References for Table 3-2 (continued)

Author(s)	Year	Article/Study
Demmers et al.	2001	Validation of Ventilation Rate Measurement Methods and the Ammonia emission from Naturally Ventilated Dairy and Beef Buildings in the United Kingdom, J. Agric. Engng Res, 79: 107-116.
Fulhage, C.D.	1998	Gaseous Emissions from Manure Management Systems, American Soc. Of Ag Engineers, ASAE Paper No. 98-4055.
Grelinger, M.	1997	Improved Emission Factors for Cattle Feedlots. Emission Inventory: Planning for the Future, Proceedings of Air and Waste Management Association, U.S. Environmental Protection Agency Conference 1:515-524 (October 28-30, 1997).
Groot Koerkamp et al.	1998a	Concentrations and Emissions of Ammonia in Livestock Buildings in Northern Europe, J. Agric. Engng Res, 70: 79-95.
Harris, D.B. and E.L. Thompson, Jr	1998	Evaluation of Ammonia Emissions from Swine Operations in North Carolina, National Risk Management Research Laboratory, U.S. EPA, Research Triangle Park, NC
Hartung, J.V., R. Phillips	1994	Control of Gaseous Emissions from Livestock Buildings and Manure Stores, J. of Agric. Engng Res, 57:173-189.
Herber., A.J., R.K. Duggirala, J. Ni, M.L. Spence, B.L.. Haymore, V.I. Adamchuck, D.S. Bundy, A.L. Sutton, D.T. Kelly, K.M. Keener	1997	Manure treatment to reduce gas emissions from large swine houses. In: Voermans J.A.M., G. Monteny, editors, Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities. Vinkeloord, The Netherlands.
Hinz, T and S. Linke	1998	A Comprehensive Experimental Study of Aerial Pollutants in and Emission from Livestock Builginds. Part 2: Results. J Agric. Engng Res, 70: 119-129.
Hobbs, PJ, TH Misselbrook, TR Cumby	1999	Production and Emission of Odours and Gases from Ageing Pig Waste. J. Agric. Engng Res, 72: 297-298.
Hoeksma, P., N. Verdoes, G.J. Monteny	1993	Two Options for Manure Treatment to Reduce Ammonia Emission from Pig Housing, In: Proceedings of the First International Symposium on Nitrogen Flow in Pig Production and Environmental Consequences, EAAP Publication No. 69, pp. 301-306, Pudoc, Wageningen, The Netherlands.
Hutchinson et al.	1982	Ammonia and Amine Emissions from a Large Cattle Feedlot, J. Environ Qual, 11: 288-293.
Jeppson, KH	1999	Volatilization of Ammonia in Deep-Litter Systems with Different Bedding Materials for Young Cattle. J. Agric. Engng. Res, 73: 49-57.
Jungbluth, T., E. Hartung	1997	Determination of the Odor Plume Boundaries from Animal Houses. In Bottcher, R.W., S.J. Hoff Editors, Proceedings of the 5th International Symposium of Livestock Environment, 1: 163-169. St. Joseph, MI: ASAE.
Koelliker and Miner	1971	1973. Desorption of Ammonia from Anaerobic Lagoons, Transactions of the American Society of Ag Eng, 16:148-151,
Kroodsma et al.	1988	Ammonia Emission from Poultry Housing Systems
Kroodsma, W., JWH Huis in 't Veld, R. Scholtens	1993	Ammonia Emission and its Reduction from Cubicle Houses by Flushing. Livestock Production Sc, 35: 293-302.
Lockyer, D.R. and B.F. Pain	1989	Ammonia Emission from Cattle, Pig, and Poultry Wastes Applied to Pasture. Environmental Pollution 56 (1989): 19-30.
Martin, J.	2000	A Comparison of the Performance of Three Swine Waste Stabilization Systems, Paper submitted to the Eastern Research Group, Inc, October 2000.
Misselbrook, T.H., B.F.Pain, D.M. Headon	1998	Estimates of Ammonia Emission from Dairy Cow Collecting Yards, J. Ag Engng Res, 71: 127-135.
Ni, J.Q., A.J. Heber, C.A. Diehl, T.T. Linn	2000	Ammonia, Hydrogen Sulphide and Carbon Dioxide Release from Pig Manure Under Floor Deep Pits, J. Ag Engn Res, 77: 53-66.

References for Table 3-2 (continued)

Author(s)	Year	Article/Study
Ni, J.Q., A.J. Heber, C.A. Diehl, T.T. Linn, C.A. Diehl, R.K. Duggirala, B.L. Haymore, and A.L. Sutton	2000	Ammonia Emission from a Large Mechanically Ventilated Swine building During Warm Weather, J. Environ Qual, 29(3).
Oosthoek, J., W. Kroodsma, P. Hoeksma	1991	Ammonia Emission from Dairy and Pig Housing Systems, Odour and Ammonia Emissions From Livestock Farming, Elsevier Science Publishing Co., Inc., New York, pp. 31-41.
Osada, T, HB Rom, P Dahl	1998	Continuous Measurement of Nitrous Oxide and Methane Emission in Pig Units by Infrared Photo acoustic Detection. Transactions of the ASAE, 41(4): 1109-1114.
Safely, L.M., Jr.	1980	An Analysis of a Metal Above-Ground Storage Tank for Handling As-Produced Dairy Manure. In: Livestock Wastes: A Renewable Resource. American Society of Agricultural Engineers, St. Joseph, Michigan. Pp. 410-411
Secrest, C.	1999	Field Measurement of Air Pollutants Near Swine Confined Animal Feeding Operations Using UV DOAS and FTIR, In: Proceedings of SPIE – The International Society of Optical Engineering, Vol. 4199, p. 98-104.
Sommer, SG, BT Christensen, NE Nielsen, JK Schjorring	1993	Ammonia Volatilization During Storage of Cattle and Pig Slurry: Effect of Surface Cover. J of Agric Sci, 121: 63-71.
Svensson, L	1994	Ammonia Volatilization Following Application of Livestock Manure to Arable Land. J Agric. Engng Res, 58: 241-260.
Tamminga, S.	1992	Gaseous Pollutants by Farm Animal Enterprises, Farm Animals and the Environment, CAB International, Wallingford, UK, pp. 345-358.
USDA	2000	Air Quality Research & Technology Transfer Programs for Concentrated Animal Feeding Operations, http://aaqtf.tamu.edu/CAFO.htm
Valli, L., S. Piccinini, G. Bonazzi	1991	Ammonia Emission from Two Poultry Manure Drying Systems, Odour and Ammonia Emissions From Livestock Farming, Elsevier Science Publishing Co., Inc., New York, pp. 50-58.
Van der Hoek, K.W.	1998	Estimating Ammonia Emission Factors in Europe: Summary of the Work of the UNECE Ammonia Expert Panel, Atmospheric Environment, 32: 315-316.
Wathes, CM, MR Holden, RW Sneath, RP White, VR Phillips	1997	Concentrations and Emission Rates of Aerial Ammonia, Nitrous Oxide, Methane, Carbon Dioxide, Dust and Endotoxin in UK Broiler and Layer Houses. British Poultry Science, 38: 14-28.
Yang, P. J.C. Lorimore, and H. Kim	2000	Nitrogen Losses from Laying Hen Manure in Commercial High-Rise Layer Facilities. Transactions of the ASAE 43(6): 1771-1780.
Zahn, JA, AE Tungand, BA Roberts, JL Hatfield.	2001a	Abatement of Ammonia and Hydrogen Sulfide Emissions from a Swine Lagoon Using a Polymer Biocover. J. Air & Waste Manage. Assoc., 51:562-573.
Zahn, JA, JL Hatfield, DA Larid, TT Hart, YS Do, AA Dispirito.	2001b	Functional Classification of Swine Manure Management Systems Based on Effluent and Gas Emission Characteristics. J. Environ. Qual, 30: 635-647.
Zahn, JA, AA Dispirito, YS Do, BE Brooks, EE Cooper, JL Hatfield	2001c	Correlations of Human Olfactory Responses to Airborne Concentrations of Malodorous Volatile Organic Compounds Emitted from Swine Effluent. J Environ. Qual, 30: 624-634.
Zhu, J., L. Jacobson, D. Schimdt, R. Nicolai.	2000a	Daily Variations in Odor and Gas Emission from Animal Facilities. App Eng in Aric, 16 (2): 153-158.
Zhu, J., L. Jacobson, D. Schimdt, R. Nicolai.	2000b	Evaluation of INPUF-2 Model for Predicting Downwind Odors from Animal Production Facilities. App Eng in Agric, 16 (2): 159-164.

Table 3-3: Odor Emission Factors

The emission factors in this table are given in odor units (OU) and detection thresholds (DT).

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	Ireland	Finish	36	Partial Slats Mech. Vent	1	1	7.7	4.3-13	OU/s-pig	1
Swine	Ireland	Finish	36	Partial Slats Mech. Vent	1	1	6.0	3.5-9.0	OU/s/pig	1
Swine	Ireland	Dry Sows	300	Full Slats Mech. Vent	1	1	12	10.7-14.7	OU/s-pig	1
Swine	Ireland	Dry Sows	1300	Full Slats Mech. Vent	1	1	10.9	5.6-23.0	OU/s-pig	1
Swine	Ireland	Weaners	NA 5-20kg	Full Slats Mech. Vent	1	1	4.7	3.2-7.1	OU/s-pig	1
Swine	Ireland	Weaners	NA 20-25kg	Full Slats Mech. Vent	1	1	11.2	7.4-14.7	OU/s-pig	1
Swine	Ireland	Finish	NA 35-95kg	Full Slats Mech. Vent	1	1	8.5	2.5-29.6	OU/s-pig	1
Poultry	Ireland	Broilers	21,000	Solid floor, wood shaving Nat. Vent	1	2	0.45		OU/s-bird	1
Poultry	Ireland	Broilers	20,000	Solid floor, wood shaving Nat. Vent	1	2	0.55		OU/s-bird	1
Poultry	Ireland	Broilers	254,000	Solid floor, wood shaving Nat. Vent	1	2	0.46		OU/s-bird	1
Poultry	Ireland	Layers	12,500	Auto manure removal Mech. Vent	1	2	0.43		OU/s-bird	1

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine Storage	MN	Finish	2,000	Lagoon (crusted)	NA	3	7.3		OU/s-m^2	2
Swine Storage	MN	Finish	3,000	Lagoon	NA	3	20.8		OU/s-m^2	2
Swine	Ohio	Finish	960	High Rise	2	4	6.2	0.3-11.1	OU/s-m^2	3
Swine	Ohio	Finish	1000	Deep Pit, Tunnel Vent	2	4	34.2	3.7-91	OU/s-m^2	3
Bovine	NE	Feeders	2,000	Feedlot—April	3	3	6.1		DT/s-m^2	4
Bovine	NE	Feeders	2,000	Feedlot—June	3	3	4.1		DT/s-m^2	4
Bovine	NE	Feeders	2,000	Feedlot—August	3	3	3.9		DT/s-m^2	4
Bovine	NE	Feeders	2,000	Feedlot--September	3	3	2.3		DT/s-m^2	4
Bovine	MN	Calves		Open lot, scrape	2	3	16.5		OU/s-m^2	6
Bovine	MN	Steers		Open lot, scrape	2	3	4.4		OU/s-m^2	6
Bovine	MN	Dairy		Open lot, scrape, deep pit	2	3	1.3		OU/s-m^2	6
Bovine	MN	Heifers		Open lot, scrape, pull plug	2	3	3.0		OU/s-m^2	6

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Poultry	MN	Broilers		Loose, caged Mech. Vent	2	4	0.45		OU/s-m^2	6
Poultry	MN	Layers		Loose, Caged, scrape, Mech. Vent	2	4	3.45		OU/s-m^2	6
Poultry	MN	Turkeys		Loose, Scrape, Mech. Vent	2	4	0.32		OU/s-m^2	6
Swine	MN	Gestation		Crates, Pull plug, deep pit, Mech. Vent	2	4	12.6		OU/s-m^2	6
Swine	MN	Farrow		pens, crates, pull plug, scrape, Mech. Vent	2	4	4.8		OU/s-m^2	6
Swine	MN	Nursey		Pens, crates, pull plug, deep pit. M and N Vent	2	4	8.66		OU/s-m^2	6
Swine	MN	Finish		Loose pens, flush, pull plug, scrape, deep pit N and M Vent	2	4	6.86		OU/s-m^2	6
Swine	MN	Boars		pens, scrape, Natural Vent	2	4	5.73		OU/s-m^2	6
Swine	MN	Gilts		Pens, deep pit Mech. Vent	2	4	2.89		OU/s-m^2	6
Swine	MN	G/F/N		crates, pull plug, Mech. Vant	2	4	0.25		OU/s-m^2	6
Swine	MN	Wean to Finish		Pens, deep pit, Nat. Vent	2	4	7.0		OU/s-m^2	6
Poultry	MN	Broilers	50,000	Mech. Vent	2	4		0.2-0.4	OU/s-m^2	5

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	MN	Gestation	550 204 kg	Mech. Vent	2	4		4.8-21.3	OU/s-m^2	5
Swine	MN	Farrow	26 205kg	Mech. Vent	2	4		3.2-7.9	OU/s-m^2	5
Swine	MN	Nursery	475 20.5kg	Mech. Vent	2	4		7.3-47.7	OU/s-m^2	5
Swine	MN	G/F	550 81.8kg	Mech. Vent	2	4		3.4-14.9	OU/s-m^2	5
Swine	MN	G/F	400 109.1kg	Natural Vent	2	4		3.5-11.3	OU/s-m^2	5
Bovine	MN	Dairy	670	Nat. Vent	3	2		2-3	OU/s-m^2	7
Bovine Storage	MN	Feeders	670	Nat. Vent	3	3		7-10	OU/s-m^2	7
Swine	MN	Finish	180 82kg	Hoop Barn Winter	2	2		1.75	OU/s/pig	8
Swine	MN	Finish	950 105kg	Curtains, Winter Mech and Nat. Vent	2	2		4.74	OU/s-pig	8
Swine	MN	Finish	180 107kg	Hoop Barn Summer	2	2		11.67	OU/s-pig	8
Swine	MN	Finish	1000 88kg	Curtains, Summer Mech. and Nat. Vent	2	2		24.0	OU/s-pig	8
Swine	Netherlands	Finish		Partially Slatted	4	1	23.8	15.2-31.4	OU/s-pig	9

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	Netherlands	Finish		Cooled surface of stored slurry below slats	4	1	19.4	10.8-28.3	OU/s-pig	9
Swine	Netherlands	Finish		Flushing system below slats done 2x/day	4	1	13.1	10.9-15.7	OU/s-pig	9
Swine	Netherlands	Weaned		slatted floors	4	1	6.8	4.0-16.3	OU/s-pig	9
Swine	Netherlands	Weaned		Cooled surface of stored slurry below slats	4	1	9.9	9.4-10.4	OU/s-pig	9
Swine	Netherlands	Weaned		Flushing system below slats done 2x/day	4	1	5.4	4.5-6 6	OU/s-pig	9
Swine	Netherlands	Nursery		Wire floors, Mech. Vent	5	4	1.76		OU/s-m^2	10
Swine Storage	Australia	Finish		Lagoon Summer	6	3		7.1-24.5	OU/s-m^2	11
Swine Storage	Australia	Finish		Lagoon Summer	6	3		12.0-24.5	OU/s-m^2	11
Swine	OK	Finish	6,000	Flush Pits/Lagoon	NA	5	18		OU/min-pig	12
Swine Storage	OK	Finish	6,000	Flush Pits/Lagoon (lagoon sampled)	NA	3		89-123	OU/min-m^2	12
Swine	Netherlands	Nursey					6.7		OU/s-m^2	13
Swine	Netherlands	Finish					19.2		OU/s-m^2	13

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	Netherlands	Finish					13.7		OU/s-m^2	13
Swine	Netherlands	Sow					47.7		OU/s-m^2	13
Swine	Netherlands	Nursey						7.3-47.7	OU/s-m^2	14
Swine	Netherlands	Finish						3.4-11.9	OU/s-m^2	14
Swine	Netherlands	Farrow						3.2-7.9	OU/s-m^2	14
Swine	Netherlands	Gestation						4.8-21.3	OU/s-m^2	14
Poultry	Netherlands	Broilers					0.1-0.3		OU/s-m^2	14
Poultry	Netherlands	Layers					0.3-1.8		OU/s-m^2	14
Poultry	Australia	Broilers					3.1-9.6		OU/s-m^2	15
Swine	US	Finish		Daily flush			2.1		OU/s-m^2	16
Swine	US	Finish		Pull Plug			3.5		OU/s-m^2	16
Swine	US	Finish		Deep Pit			5.0		OU/s-m^2	17

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	Netherlands	Finish						6.7-47.7	$OU/s\text{-}m^2$	18
Swine	Netherlands	G/F		Mech. Vent				0.3-15.1	$OU/s\text{-}m^2$	19
Swine Application	Australia			Feedlot		3		128-160	$OU/s\text{-}m^2$	20
Bovine Application						3		937-22.7	$OU/s\text{-}m^2$	20
Bovine	Australia	Feeder						14-840	$OU/s\text{-}m^2$	21
Swine	Australia	Finishing		Flushing			150		OU/s-pig	22
Swine								0.25-12.6	$OU/s\text{-}m^2$	23

Codes for "Odor Method" in Table 3-3

1: 40ppb n-butanol for standards and 50% agreement among 8 panel members as the DT.
2: ASTM 679-91 and European Stand ODC 543.271.2-629.52
3: CEN Method 13725
4. Dutch Standard
5: CEN TC264
6: New Zealand Stand 4323.3

Codes for "Ventilation Method" in Table 3-3

1. Hot wire anemometer
2. CO2 balance
3. Wind Tunnel (flux chamber)
4. Manufacturer specs
5. Heat balance

References for Table 3-3

1. E.T. Hayes et al. ASAE, Las Vegas Nev., July, 2003. Paper #034082.
2. J.R. Bicudo et al. ASAE, Sacramento, CA, July, 2001. Paper # 014092.
3. R.R. Stowell et al. ASAE, Chicago, IL, July 2002. Paper # 024122.
4. R. Duyson, et al. ASAE, Las Vegas, Nev., July, 2003. Paper #034109.
5. J. Zhu et al. Applied Eng. in Agr., Vol 16(2), 153-158, 1999.
6. S.L. Wood et al. ASAE Sacramento, CA., July 2001. Paper #014043.
7. H. Bicudo et al. 5th In't Dairy Housing Proceedings, Fort Worth, TX, Jan, 2003.
8. L.D. Jacobson et al. Air Pollution from Ag. Operations III, Raleigh, NC, Oct., 2003.
9. G. Mol. Air Pollution from Ag. Operations III, Raleigh, NC, Oct., 2003.
10. T.T. Lim et al. Trans ASAE, Vol 44(5), 1275-1282. 2001.
11. G. Galvin et al. Air Pollution from Ag. Operations III, Raleigh, NC, Oct., 2003.
12. A.J. Heber et al. PAAQL Executive Summary, Purdue Un., June, 2004.
13. N.W. Ojink, et al. ASAE, St. Joe, MI. Paper 97-4036, June, 1999.
14. J. Zhu et al. ASAE, St. Joe, MI. Paper 99-4146. June, 1999.
15. J.K. Jiang et al. Report on Odor Emissions, Australia, 1998.
16. A.J. Heber et al. Emission From G-F Buildings. Report to Nat. Pork Council, 2001.
17. A.J. Heber et al. Odor Emission Data from Swine Confinements. Proceedings In't Conf. on Odor, Water Quality and Nutrient Management and Socioeconomic Issues, Des Moines, IA 1996.
18. N. Verdes et al. Odor Emissions from Pig House with Low Ammonia Emissions. Proceedings In't Symp. on Ammonia and Odor Control from Animal Production Facilities, Netherlands, Oct. 1997.
19. J.V. Klanenbeck et al. Proceeding 5th In't Symp. on Agricultural Wastes. Chicago, 1985.
20. B.F. Pain et al. Odor and Ammonia Emissions Following Application of Pig or Cattle Slurry. In Volatile Emissions from Livestock Farming and Sewage Operations. Eds V. C. Nelson et al., Elsevier Pub., New York, NY, 1988.
21. P.J. Watts. Trans. ASAE 37(2) 629-36. 1994.
22. P.J. Watts. Final Report of Project No. 1/1503. November, 1999.
23. Gay et al. In publication, 2003.

Table 3-4 – Particulate Matter (PM_{10}) Emission Factors

Species	Location	Type	Size/ Number/Units	PM10 Emission Factor Average/median	Range	Units	Reference
Beef	USA	Dry lot	500 animal unit (au)	12.7 lb/yr/au	5.4-20.0	lb/yr/au	1, 2
Dairy	USA	Dry lot	500 au	2.3 lb/yr/au	N/a		1
Swine	USA	Flush house	500 au	8.0/8.8 lb/yr/au	4.6-13.0	lb/yr/au	3, 4
Swine	USA	House w/pit recharge	500 au	8.0/8.8 lb/yr/au	4.6-13.0	lb/yr/au	3, 4
Swine	USA	House w/pull plug pit	500 au	8.0/8.8 lb/yr/au	4.6-13.0	lb/yr/au	3, 4
Swine	USA	House w/pit storage	500 au	8.0/8.8 lb/yr/au	4.6-13.0	lb/yr/au	3, 4
Poultry Chicken	USA Europe	Broiler house w/bedding	500 au	8.2 lb/yr/au	2.9-14.0	lb/yr/au	5, 6
Poultry Turkey	USA Europe	Turkey house w/bedding	500 au	18.7/18.7 lb/yr/au	1.4-36.0	lb/yr/au	5, 6
Cattle	USA	Feed yards	1000 hd/d	15 lb/1000 hd/d			7
Dairy	USA	Free stall	1000 hd/d	4.4 lb/1000 hd/d			7
Swine	UK	Housed livestock		573 lbs/1000 hd			8
Dairy	UK	Housed livestock		284 lbs/1000 hd			8
Broilers	UK	Housed livestock		129.6 lbs/1000 hd			8
Beef	UK	Housed livestock		92.4 lbs/1000 hd			8
Poultry	UK	Housed livestock		163 lbs/1000 hd			8
Laying hens	UK	Housed livestock		42.8 lbs/1000 hd			8

References for Table 3-4

1. USDA. 2000. Confined Livestock Air Quality Subcommittee, J.M. Sweeten, Chair. U.S. Department of Agriculture, Agricultural Air Quality Task Force Meeting, Washington, DC. Air Quality Research & Technology Transfer Programs for Concentrated Animal Feeding Operations.
2. Grenlinger, M.A. 1997. Improved Emission Factors for Cattle Feedlots. Emission Inventory: Planning for the Future, Proceedings of Air and Waste Management Association, U.S. Environmental Protection Agency Conference. Volume 1, pp. 515-524. October 28-30.
3. Grelinger, M.A. and A. Page. 1999. Air Pollutant Emission Factors for Swine Facilities. Air and Waste Management Conference Proceedings. Pp. 398-408. October 26-28.
4. Takai et al. 1991
5. Grub, w., C.A. Roolo, J.R. Howes. 1965. Dust Problems in Poultry Environments. Transactions of the American Society of Agricultural Engineers. Pp. 338-39, 352.
6. Takai, H., S. Pederson, J.O. Johnson, J.H.M., Mertz, P.W.G. Groot Koerkamp, G.H. Uenk, V.R. Phillips, M.R. Holden, R.W. Sneath, J.L. Short, R.P. White, J. Hurtung, J. Seedorf, M. Schroder, K.H. Linker, C.M. Wathes. 1998. Concentrations and Emissions of Airborne Dust in Livestock Building in Northern Europe. Journal of Agricultural Engineering Resources 70:59-70
7. Goodrich, L.B., Parnell, C.B., Makhtar S., Lacey, R.E., Shaw, B.W Preliminary PM10 Emission Factors for Free stall Dairies. Department of Biological And Agricultural Engineering, Texas A&M University, College Station, TX. Paper # 024214 at 2002 ASAE Annual International Meeting.
8. The UK Emission Factor Database, National Atmospheric Emissions Inventory, www.naei.org.uk/emissions/index.php, 2000.

4.0 Dispersion Modeling

4.1 Executive Summary

The Dispersion Modeling workgroup recommends application of the American Meteorological Society / Environmental Protection Agency Regulatory Model (AERMOD)[3] for estimation of odor, hydrogen sulfide and ammonia impacts from AFOs. Additionally, the workgroup makes two sub-recommendations:

1. Review of new or enhanced dispersion modeling systems should be conducted on an annual basis in order to take advantage of emerging scientific advances associated with estimation of the dispersion of odor, hydrogen sulfide and ammonia emissions from AFOs.

2. Investigation of proper model configuration and setting selection is necessary to more fully evaluate the suitability of the AERMOD dispersion modeling system for estimating odor, hydrogen sulfide and ammonia concentrations at separated locations.

Development of these recommendations was accomplished through the voluntary participation of interested stakeholders and staff from the DNR.

4.2 Purpose

The charge of the workgroup on dispersion modeling was to identify modeling tools currently available that can be used to assess ambient concentrations of odor, hydrogen sulfide and ammonia from AFOs.

Dispersion models are routinely used to estimate the concentration of pollutants emitted into the atmosphere. These models use mathematical representations of physical and chemical atmospheric processes in combination with characterization of air pollutant emissions to simulate the transport and diffusion of pollutants from a source of release. Various types of dispersion models have been developed to represent different types of emission release scenarios. The most commonly used types of dispersion model are those based on proven Gaussian dispersion methodology. Employed as the preferred type of model for simulating air pollutant emissions from industrial sources, this class of model has undergone significant scientific scrutiny and peer review for application in assessing pollutants with National Ambient Air Quality Standards. The resulting user base and development community includes federal, state, private and educational entities.

Additional classes of models have been developed to assess a range of requirements for estimating pollutant concentrations. These models include emergency release models used to estimate danger zones from the accidental or intentional release of hazardous substances to models designed to evaluate the transport of pollutants on a global scale.

Independent of the type or class of model employed in a particular study, models allow users to evaluate the results of multiple scenarios on multiple locations in a manner where variables can be controlled. In the case of dispersion modeling for the protection of air quality in the vicinity of an industrial facility, model simulations allow the facility and regulatory agency to evaluate air quality concerns for multiple configurations prior to construction or changes at the facility. In this way, models are capable of helping

[3] http://www.epa.gov/scram001/7thconf/aermod/aermodug.pdf

to mitigate not only adverse air quality but also unnecessary expenses associated with identifying and rectifying problems after an air pollution source is constructed and operating.

Though models produce estimates based on a simplified representation of real world conditions, they in effect establish “virtual” monitors, or receptors that can be located in the model as specified by the user. In reality, siting of ambient air quality monitors is limited by the need for nearby resources such as electricity and surrounding land use or ownership issues. Additionally, the acquisition, siting and continued operation and maintenance of ambient air quality monitors is resource intensive whereas hundreds or thousands of model receptors can be easily established in a model.

Unlike actual measurements of air pollutant concentrations at ambient air monitoring sites, model results are estimates of pollutant concentrations. As such, the accuracy of these estimates is vulnerable to errors resulting from inadequate scientific formulation or inaccurate input and runtime parameters. As noted above, for application to industrial sources of certain air pollutants various models have been thoroughly investigated as to the accuracy for estimating resulting concentrations. However, less information is available for the application of models for estimating downwind concentrations of odor, hydrogen sulfide or ammonia from AFOs. This is complicated by the fact that the science of air quality issues associated with AFOs continues to evolve.

Of critical importance to the ability of any dispersion model to accurately estimate downwind concentrations of odor, hydrogen sulfide or ammonia is the availability of accurate and realistic estimates of pollutant emission rates from multiple types of sources. A single downwind pollutant concentration, whether measured or modeled, represents the sum of pollutant concentrations at that point which have been transported from multiple sources at differing locations. For an AFO this may include sources such as multiple exhaust fans and a lagoon, each of which may have different individual impacts at a downwind location. Many models are capable of simulating multiple types and numbers of pollutant emission sources simultaneously. However, the ability of the model to accurately estimate downwind pollutant concentrations remains highly dependent on an accurate estimate of pollutant emission rates from each source.

The Dispersion Modeling workgroup was formed to assess general issues such as those discussed above and provide answers for several specific questions. The following list of questions was provided as a starting point for the group’s consideration:

1. What models are available that can accurately predict concentrations of pollutants downwind from a source?
2. What is the best model available that most accurately predicts concentrations of pollutants downwind from a source?
3. How difficult is the model to use?
4. What type of computer hardware and software is required to run the model?
5. How is the model obtained?
6. What are the inputs into the model and how easily are they obtained?
7. Are there any associated costs with purchasing or running the model (such as purchasing meteorological data)?
8. What physical mechanisms are represented within the model, what physical mechanisms are needed?
9. What atmospheric chemical processes affect odor, hydrogen sulfide and ammonia?
10. How far can odor, hydrogen sulfide and ammonia be expected to be transported?

Participants in the workgroup answered these questions and completed the group's charge of recommending a model or models that could be used to evaluate pollutant concentrations downwind from AFOs. It should be noted that while this group worked to identify a model proven for validity and accuracy specific to odor, hydrogen sulfide and ammonia from AFOs, the group concluded that the present scientific evidence is insufficient to identify such a model. Instead, the recommendation of this group identified the leading candidate for such air quality studies. Additional effort on comparing model predictions to observations is necessary. In the interim, the AERMOD dispersion modeling system can provide insight into not only the dispersion of odor, hydrogen sulfide and ammonia from AFOs, but possibly more important, insight into the relative efficacy of best management practices.

4.3 Methodology

The workgroup initiated efforts with a review of the goals for the group. In particular, participants identified the need to align the goals of the group with feasible deliverables. Development of new dispersion modeling systems and testing of existing systems for accuracy was considered beyond the scope of this effort. As a result, investigation by the group was directed toward identifying the best dispersion modeling system currently available which could estimate the relative change in pollutant concentrations resulting from changes in site management such as application of various best management practices. Focus was directed toward two primary areas; reviews of literature concerning dispersion modeling of odor, hydrogen sulfide and ammonia and model characteristics identified as critical to successfully simulating pollutant emissions from AFOs.

Four fields of generalized capabilities for candidate dispersion modeling systems were identified. These fields are:

- Emissions representation
- Physical atmospheric processes
- Chemical atmospheric processes
- Receptor / concentration (output) representation

4.3.1 Emissions Representation

AFOs contain multiple sources and types of sources of emissions of odor, hydrogen sulfide and ammonia. To be successful in estimating pollutant concentrations or the relative efficacy of best management practices, a dispersion modeling system must be able to represent the applicable types of sources. Examples of source types include indoors versus outdoors pits, above ground versus below ground, mechanical exhaust vents and naturally or curtain ventilated operations. Additionally, candidate models must have the ability to vary emission rates with time individually.

The emission source types existing at an AFO can be represented by several standard model representation schemes. Exhaust fans, for example, can be treated in a manner similar to how stacks at industrial sources are modeled. Lagoons and pits can be treated as area sources where the emissions are originating from a surface layer. In addition the height above ground of these release points or areas must be variable.

4.3.2 Physical Atmospheric Processes

Fundamentally, dispersion models represent how pollutants are transported by the wind from one point to another. During this transport, atmospheric mixing processes change the original pollutant concentration through dilution and/or deposition. As pollutants are transported further from their point of release this dispersion continues to reduce the per unit concentration for the particular set of pollutants released from that point at a particular time. In addition, multiple releases from multiple locations may be mixed and transported in such a way as to converge at a downwind receptor point, and the per unit concentration a that point may not necessarily be less than that at the initial release points. These are examples of the physical processes that a candidate dispersion model must account for.

4.3.3 Chemical Atmospheric Processes

Changes in the downwind concentration of pollutants may be affected by atmospheric chemical process in addition to the physical process discussed above. For example, sulfur dioxide, a common pollutant emitted from combustion, undergoes various atmospheric chemical processes during its atmospheric lifetime. Over time, sulfur dioxide may react with ammonia to produce ammonia sulfate particulate matter. As part of the efforts of the workgroup, the need and availability of model formularizations that address atmospheric chemical processes for odor, hydrogen sulfide and ammonia were reviewed.

Complicating this review is the short spatial and temporal scales at which a candidate model for estimating downwind pollutant concentrations or relative efficacy of best management practices is expected to perform. The types of issues targeted for modeling analysis, such as estimated odor reduction from application of a specific best management practice, are generally local, or within approximately 3.1 miles (5 kilometers). At this distance, a light breeze of seven miles per hour will transport pollutants beyond five kilometers in approximately 30 minutes or more than a mile in ten minutes. As such, any chemical process must act on a time scale of minutes to be critical to the type of near-field concentration estimates that are the focus of this type of modeling effort.

Review of applicable literature identified pertinent discussion of treatment of chemical processes associated with emissions from AFOs. A study conducted by Earth Tech, Inc.,[4] confirms that for short spatial and temporal scales significant chemical transformation of pollutants from AFOs is negligible. As such, the need for mechanisms for treatment of atmospheric chemical processes was determined not to be critical at this time in the selection of a candidate modeling system. However, while the chemical formulation was not used as a determining factor in the final model selection, such model capabilities were reviewed throughout the process.

4.3.4 Receptor / Concentration (Output) Representation

Atmospheric dispersion models are designed to provide estimates of pollutant concentrations at a given location for a given time period. In regulatory applications the time periods in question are established in the National Ambient Air Quality Standards. For example, concentrations of sulfur dioxide considered harmful vary depending on the duration of exposure. These duration’s are expressed as concentrations during a specific averaging period. For the example of sulfur dioxide, concentrations are evaluated on a 3-hour, 24-hour and annual basis. For odor, hydrogen sulfide and ammonia, various averaging periods could be applicable depending on the purpose of the application. For the purpose of this workgroup, model criteria concerning utility of model output was based on the ability of a model to be configured to assess multiple averaging periods.

Using these general criteria as a guide, the workgroup reviewed available models. A three phase approach was applied sequentially to eliminate candidate models from further consideration with the purpose of identifying one or more models that could be used to estimate downwind concentrations of

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[4] Earth Tech, Inc. Final Technical Work Paper for Air Quality and Odor Impacts. Prepared for the “Generic Environmental Impact Statement on Animal Agriculture.” Earth Tech, Inc., Minneapolis, MN, March 2001.

odor, hydrogen sulfide and ammonia, and assess the relative efficacy of best management practices. Application and the resulting decisions are further discussed in the following sections of this document.

4.4 Candidate Models

The Environmental Protection Agency (EPA) Support Center for Regulatory Air Models (SCRAM) website[5] provided the initial list of candidate models. The website, operated and maintained by EPA, provides documentation and guidance on atmospheric dispersion models that support regulatory programs required by the Clean Air Act. Source codes and technical data, including information on basic design and purpose, are also provided for most models.

EPA classifies models as either preferred or recommended. Models deemed by EPA to be the most appropriate models available for regulatory applications are classified as "preferred", and are listed in Appendix A of the *Guideline on Air Quality Models (*published as Appendix W of 40 CFR Part 51)[6]. Refined air quality models for use on a case-by-case basis for individual regulatory applications are classified as "recommended". A justification for using a recommended model must be submitted prior to use for regulatory purposes. The list of candidate models contained the complete set of both preferred and recommended models.

In addition to those models found on the SCRAM website, several research-grade models were placed on the list of candidate models, including CAM[7], Farm Emissions Model & National Practices Model (FEM-NPM)[8] and STINK[9]. These proprietary models have typically been developed at colleges and universities to suit a specific need or purpose. Several models that are used in foreign countries to support regulatory programs were also added to the list, and these included Austrian Odour Dispersion Model (AODM)[10], Australian Plume Model (AUSPLUME)[11], and Fine Resolution Atmospheric Multi-Pollutant Exchange (FRAME)[12]. Although not recommended for use by EPA, these models have also undergone analysis and peer-review, and may have similar capabilities to air dispersion models used in the United States. Finally, the Integrated Puff (INPUFF-2)[13] and Computer-Aided Management of Emergency Operations/Arial Locations of Hazardous Atmospheres (CAMEO-ALOHA)[14] models were added to the list based on information provided in available literature. The model OFFSET[15], developed by the University of Minnesota, was not included on the list of candidate models because it is designed primarily as a tool used

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[5] http://www.epa.gov/ttn/scram/

[6] U.S. EPA. Revision to the Guideline on Air Quality Models: Adoption of a Preferred Long Range Transport Model and Other Revisions; Final Rule. 40 CFR Part 51, 2003.

[7] Bundy, D.S., and S. Hoff. Personal Communication. 2004

[8] Pinder, R. W., N. Anderson, R. Strader, C. Davidson, and P. Adams. Ammonia Emissions from Dairy Farms: Development of a Farm Model and Estimation of Emissions from the United States. 12th International Emission Inventory Conference "Emissions Inventories – Applying New Technologies," San Diego, CA, April 29 – May 1, 2003.

[9] Smith, R.J. and P.J. Watts. Determination of Odour Emission Rates from Cattle Feedlots: Part 2, Evaluation of Two Wind Tunnels of Different Size. Journal of Agricultural Engineering Research, 58: 231-240, 1994.

[10] Schaugerger, G., M. Piringer, and E. Petz. Diurnal and Annual Variation of the Sensation Distance of Odour Emitted by Livestock Buildings Calculated by the Austrian Odour Dispersion Model (AODM). Atmospheric Environment, 34: 4839-4851, 2000.

[11] EPAV (Victorian Environmental Protection Agency). AUSPLUME Gaussian Plume Dispersion Model User Manual. Environment Protection Authority, Government of Victoria, Melbourne, Australia, 2000.

[12] Dore, Anthony, et. Al. Modeling the Transport and Deposition of Sulphur and Reduced and Oxidised Nitrogen in the UK. Status Report to DEFRA, as a contribution to Long Range Transport of Pollutants in the UK. July, 2003. Available at: http://www.frame.ceh.ac.uk/reports.html.

[13] Petersen, W.B. and L.G. Lavdas. INPUFF 2.0 A Multiple Source Gaussian Puff Dispersion Algorithm – User's Guide. EPA/600/8-86-024. August, 1986.

[14] http://response.restoration.noaa.gov/cameo/cameo.html

[15] Jacobson, L., D. Schmidt, and S. Wood. OFFSET Odor From Feedlots Setback Estimation Tool. University of Minnesota Extension Service, 2002. Available at: http://www.extension.umn.edu/distribution/livestock systems/DI7680.html

to site new facilities for construction. OFFSET is not capable of predicting concentrations downwind of a facility.

The complete list of fifty-seven candidate models identified for consideration can be found in Table 4-1. The list was not intended to be an all-inclusive, comprehensive list of air dispersion models, but rather a list of those models supported by EPA or those where literature was readily available that indicated the model may be appropriate. After the list was finalized, a three phase approach was used to eliminate models from the list until only the most appropriate model(s) able to accurately predict the dispersion of ammonia, hydrogen sulfide, and/or odors from AFOs remained.

4.4.1 Phase 1

Thirty-three models were eliminated from consideration during Phase 1. During this phase, models whose cursory descriptions indicated that they would not be suitable or relevant for the purposes of the workgroup were removed. Only the basic capability of the model, or what the model could actually be expected to accomplish, was considered. For example, the Buoyant Line and Point Source Model (BLP)[16], a model designed to handle unique situations associated with aluminum reduction plants, and the Assessment System for Population Exposure Nationwide (ASPEN)[17] model, which is used to estimate toxic air pollutant concentrations over a large scale domains, were both removed. Models were also eliminated if the basic descriptions indicated that one model was superior over another. For example, some models are designed as "screening models" and are used to provide a rough, conservative estimate of concentrations prior to completing a more refined and accurate analysis. Therefore, a screening model was removed if a similar refined model was also on the list. Finally, models often improve over time, with some features of an older model being absorbed into newer, more accurate models. For this reason, only the most recent version of a model was considered during this process. A complete list of the models that were considered in Phase 2 is found in Table 4-1.

4.4.2 Phase 2

During Phase 2, the remaining twenty-four models were researched and reviewed to determine if they would be suitable for predicting concentrations of ammonia, hydrogen sulfide, and/or odors downwind of a source. Basic criteria, such as what the models require for full implementation in terms of license fees, training costs, hardware, data inputs and also purpose and capability, were used to evaluate the models. The resulting evaluations identified six remaining models that required more extensive research to determine their applicability towards AFOs. The list of remaining models included AERMOD, ADMS 3[18], AODM, CALPUFF[19], INPUFF-2, and STINK.

During phase 2, the Industrial Source Complex – Short-Term Model 3 (ISC-ST3) was removed from consideration. Although ISC-ST3 is currently EPA's preferred model for use in most regulatory analyses, the group found AERMOD to be superior in several key areas, such as advanced meteorological profiles, concentration distribution, and treatment of complex terrain, when compared directly to ISC-ST3.

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[16] Schulman, L. and J. Scire. Buoyant Line and Point Source (BLP) Dispersion Model User's Guide. Environmental Research & Technology, Inc., 1980.

[17] U.S. EPA. User's Guide for the Assessment System for Population Exposure Nationwide (ASPEN, Version 1.1) Model. EPA-454/R-00-017, April, 2000.

[18] Cambridge Environmental Research Consultants Ltd. (CERC). ADMS 2 User Guide Version 3.2. CERC, 3 Kings Parade, Cambridge, CB2 1SJ, UK. July, 2004.

[19] Earth Tech, Inc. CALPUFF Training Course Manual. Central States Air Resource Agencies Association (CenSARA), Kansas City, KS, November 17-19, 2003.

4.4.3 Phase 3

A detailed list of criteria was developed in Phase 3 of the evaluation to aid both in determining if the model has the capability to produce the desired output types, and also to compare the models amongst themselves. The list of criteria included:

1. Is the model user-friendly? Do you need to know a computer language? Does the model have a user interface, etc.?
2. What type of computer(s) is/are needed to run the model? Can the model run on a personal computer or does it need additional hardware, etc.?
3. Can in-house experience or skills be used to run the model? Will the model take extensive training to run?
4. What is the cost of the model? Is the software free or are there associated costs?
5. Does the model adequately characterize AFO emission source types? Does the model allow more than one source to be input? Does the model allow for different types of sources (point, area, line, pit, etc.)?
6. Does the model allow for wet and/or dry deposition?
7. Does the model adequately represent atmospheric chemical processes? Does the model provide specific processes for NH3, H2S, or odor, or does it treat all pollutants the same?
8. Are the format and/or type of model output usable for the evaluation of best management practices?
9. Is the model EPA approved? Preferred?
10. Does the model have both short and long term averaging periods?
11. Is the model designed for the appropriate size scale (1-5 km)?
12. What is the model's input data needs (meteorological data, terrain, etc.)?
13. Does the model account for building downwash?
14. Has the model been used previously for an AFO application? Is there any research that documents the use of the model for predicting NH3, H2S or odors from AFOs?

Each model was then extensively researched to determine to what extent it met the aforementioned criteria, to the extent possible.

4.4.3.1 AERMOD

The American Meteorological Society / Environmental Protection Agency Regulatory Model (AERMOD) exhibited the best collection of features of the six models that underwent extensive review. As such, the workgroup recommends application of AERMOD for estimation of odor, hydrogen sulfide and ammonia emissions from AFOs. Specific AERMOD features that make it suitable for this purpose include:

1) User-friendliness,
2) Able to run on a personal computer,
3) Does not take extensive training to operate,
4) Software available at no cost,
5) Able to characterize point, volume, area, area-polygon and area-circle source types,
6) Sophisticated in its handling of near-surface atmospheric mixing,
7) Could be used for the evaluation of best management practices,
8) Capable of handling both short and long term averaging periods,
9) Applicable to appropriate spatial scale,
10) Able to account for complex terrain (where downwind terrain is higher than the release height), and

11) Able to account for building downwash.

In addition to these features, Koppulu et. al.[20] compared AERMOD to STINK, and found the models comparable for the dispersion of odorous compounds.

One drawback to AERMOD is that the model is limited in its capability to treat atmospheric chemical processes, and odors are not explicitly part of the model. There are no specific processes included for treating ammonia or hydrogen sulfide. Only reactions involving sulfur dioxide are modeled using a simple chemistry scheme. However, AERMOD still compared well to the other models in this regard.

In addition, the current publicly available version of AERMOD does not have the ability to calculate wet and dry deposition. However, this functionality is currently being incorporated and beta testing is underway. It is anticipated that both wet and dry deposition will be included as a standard feature in future versions of AERMOD.

4.4.3.2 ADMS 3

The Atmospheric Dispersion Modeling System (ADMS 3) is maintained by Cambridge Environmental Research Consultants Ltd. (CERC) and contains several features that demonstrated potential usefulness for the purposes of the workgroup. ADMS 3 has the ability to handle both hourly sequential and statistical meteorological data, was classified as user friendly, provided for both wet and dry deposition, performed analyses on the appropriate scale, allowed for appropriate source types, and was able to account for complex terrain. However, the model also contained several inherent limitations, including:

1) Would require extensive training to operate,
2) Limitations on the number of area, line, and volume sources that could be used in the model for a single run (6 is the maximum), and
3) Potential cost concerns with both software (roughly $3,000) and training courses, which are only offered in the United Kingdom.

Despite the limitations, ADMS 3 does compare well with AERMOD in the treatment of dispersion and complex effects, and provides a variety of other options that are unavailable in AERMOD (short term fluctuations for odors, condensed plume visibility, puff release, and special treatment for coastline areas). However, the model did not compare well when considering the potential costs involved for both software and training.

4.4.3.3 AODM

The Austrian Odour Dispersion Model (AODM) uses standard Gaussian plume equations coupled with an emission module and a module to calculate instantaneous odor concentrations to evaluate downwind odor concentrations. The assessment of AODM indicated that the model would not be appropriate to use for the purposes of the workgroup, with respect to odor. In addition to being proprietary and therefore possibly unavailable to the public, AODM's drawbacks included:

1) The inability to predict concentrations from other than a single point source,
2) The inability to handle either wet or dry deposition,
3) A lack of reliability for distances less than 100 meters,

[20] Koppolu, L., D.D. Schulte, S. Lin, M.J. Rinkol, D.P. Billesbach, and S.B. Verma. Comparison of AERMOD and STINK for Dispersion Modeling of Odorous Compounds. Paper No. 024015. ASAE Annual International Meeting, Chicago, Illinois, July, 2002.

4) The ability to handle only short, half-hour averaging periods,
6) An inability to deal with complex terrain or building downwash,
7) A lack of preferred or approved status with the EPA, and
8) A need for continuous fan exhaust rate data as a proxy for confinement temperatures.

While the model did demonstrate user-friendliness and minimal training requirements, AODM suffered from too many limitations to be used for the purposes of the workgroup.

4.4.3.4 CALPUFF

The non-steady state Lagrangian California Puff Model (CALPUFF) was recently elevated to EPA preferred model status based on its ability to simulate long-range phenomena such as visibility and acid deposition. In addition to backing by EPA, CALPUFF's strengths include:

1) Software is available at no cost,
2) Allows for both wet and dry deposition,
3) Contemplates appropriate source types and averaging periods, and
4) Handles building downwash and complex terrain.

Although CALPUFF can be used to predict downwind concentrations of ammonia, hydrogen sulfide and odors, the model is designed primarily for spatial scales beyond 5 kilometers, and therefore required more sophisticated meteorological data inputs than any of the other models reviewed. Previous applications of CALPUFF for AFOs focused on gauging the impact of a group of facilities over a county-wide area, rather than just a single facility on a local scale.[21]. In addition, Jacobson et. al.[22], states that CALPUFF is recommended for multi-facility applications, based on the technical advantages it provided for near-calm scenarios.

The goal of this workgroup was to identify a model or models that could accurately predict concentrations of ammonia, hydrogen sulfide or odors from a single facility. If future needs dictate a cumulative analysis over a geographic area containing multiple AFOs, CALPUFF may be a candidate model for such an exercise.

4.4.3.5 INPUFF -2

EPA developed the Integrated Puff (INPUFF-2) model to simulate the dispersion of buoyant or neutrally buoyant gas releases from both stationary and moving point sources. Although the effectiveness of INPUFF-2 in predicting odor concentrations downwind of a source or sources has been demonstrated[23], the model was found to be limited in several key aspects necessary for the accurate prediction of ammonia, hydrogen sulfide, or odors from an AFO. These limitations include:

1) Limited to point sources only, and unable to account for area or volume sources,
2) Unable to account for dry deposition,

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[21] Pratt, G. Recommendations on the Combined Impact of Air Emissions from Multiple Feedlots – Draft. Minnesota Pollution Control Agency, November, 1999.
[22] Jacobson L.D., R. Moon, and J. Bicudo, et. Al. Generic Environmental Impact Statement on Animal Agriculture: Summary of the Literature Related to Air Quality and Odor. University of Minnesota, College of Agriculture, Food, and Environmental Sciences, 1999. Available at: http://www.mnplan.state.mn.us/pdf/1999/eqb/scoping/aircha.pdf
[23] Zhu, J., L. Jacobson, D. Schmidt, and R. Nicolai. Evaluation of INPUFF-2 Model for Predicting Downwind Odors from Animal Production Facilities. Applied Engineering in Agriculture, 16(2): 159-164, 2000.

3) Output is average of release durations, so unable to produce concentrations for various averaging periods,
4) Not recommended for modeling dense gas dispersions (such as hydrogen sulfide), and
5) Unable to account for complex terrain or building downwash.

As the limitations indicate, more flexibility is needed within the model to evaluate the full range of diverse animal facility types.

4.4.3.6 STINK

STINK is a research-grade, Gaussian plume model that was developed in Australia[24]. The workgroup was unable to obtain enough information on the specific features of STINK to make a practical decision on this model possible. Therefore, the model was dropped from consideration until more information becomes available or is brought to the attention of the workgroup.

4.5 Conclusion

AERMOD represents the state of the science in local scale dispersion modeling and therefore application of the AERMOD computer modeling system for atmospheric dispersion modeling of ammonia, hydrogen sulfide and odor from AFOs on a spatial scale of 5 kilometers or less is recommended at this time. Additional investigation into the absolute accuracy of modeled pollutant concentrations is also suggested.

Review of model applicability for estimating pollutant concentrations of ammonia, hydrogen sulfide and odor from AFOs yield many similarities to other, more common, dispersion modeling applications. These similarities include the release characteristics of pollutant emission sources at AFOs in addition to spatial and temporal scales commonly reviewed for industrial applications. Less correlation with common applications exist for unique pollutant specific characteristics and emission factor information.

In general, the field of dispersion modeling of ammonia, hydrogen sulfide and odor from AFOs is relatively new as compared to application of atmospheric dispersion models for federally mandated criteria pollutant emissions from industrial sources. It should be noted however, that the fundamental atmospheric processes of pollutant dispersion and transport are common to all sources and species of pollutant emissions regardless of the nature of the emitting process. This similarity allows future evaluation of absolute model performance for ammonia, hydrogen sulfide and odor to take advantage of the thirty plus years of advances in computational representation of atmospheric pollutant dispersion processes.

[24] Smith, R.J. and P.J. Watts. Determination of Odour Emission Rates from Cattle Feedlots: Part 2, Evaluation of Two Wind Tunnels of Different Size. Journal of Agricultural Engineering Research, 58:231-240, 1994.

Table 4-1

List of Candidate Models

Model	Eliminated in Phase 1	Eliminated in Phase 2	Eliminated in Phase 3	Recommended Model
ADAM		X		
ADMS 3			X	
AERMOD				X
AFTOX	X			
AODM			X	
ASPEN/EMS-HAP	X			
AUSPLUME		X		
AVACTA II		X		
BLP	X			
CALINE 3	X			
CALPUFF			X	
CAL3QHC/CALQHCR	X			
CAM		X		
CAMEO/ALOHA		X		
CAMx	X			
CDM2	X			
CMAQ	X			
COMPLEX 1	X			
CTDMPLUS		X		
CTSCREEN	X			
DEGADIS		X		
EKMA	X			
ERT	X			
FEM-NPM		X		
FRAME		X		
HGSYSTEM	X			
HOTMAC	X			
INPUFF 2			X	
ISCST3		X		
LONG Z	X			
MESOPUFF II	X			
MTDDIS	X			
OB ODM	X			
OCD	X			
OZIPRZ	X			
PAL		X		
Panache		X		
PLUVUE II	X			
PPSP	X			
RAPTAD		X		
RAM		X		
RPM IV		X		

Model	Eliminated in Phase 1	Eliminated in Phase 2	Eliminated in Phase 3	Recommended Model
RTDM 3.2		X		
SCIPUFF	X			
SCREEN 3	X			
SCSTER	X			
SDM	X			
SHORT Z		X		
Simple Line Source	X			
SLAB		X		
STINK			X	
TSCREEN	X			
UAM IV	X			
UAM V	X			
VALLEY	X			
VISCREEN	X			
WYNDVALLEY	X			

5.0 Conclusion

The Iowa Department of Natural Resources Animal Feeding Operations Technical Workgroup was convened on February 5th and concluded December, 2004. This workgroup allowed the Iowa Department of Natural Resources an opportunity to gain valuable insight and expertise from individuals with technical knowledge as part of a continuing effort to develop a working understanding of the complex technical issues involved in air quality issues associated with animal feeding operations (AFOs). This report summarizes the processes, assumptions, data, and recommendations of each of the three workgroups in the areas of best management practices (bmp's), air emissions characterization, and dispersion modeling.

The findings of the bmp workgroup indicate that current technologies are available to producers to reduce air emissions from livestock operations. These technologies are summarized in Chapter 2.0 of this report, and can also be found at the following web address: http://extension.agron.iastate.edu/immag/pubsodors.html. Adoption of these technologies by producers will benefit the air quality on the farms themselves, at nearby residences, and the overall environment by reducing air emissions.

The Air Emissions Characterization workgroup summarized available emission factors for ammonia, hydrogen sulfide, particulate matter, and odors. The emission factors are listed in Tables 3-1 through 3-4 to provide the public with one centralized location to find emission factors that may be used to estimate emissions from AFOs.

The Dispersion Modeling workgroup recommends application of the American Meteorological Society / Environmental Protection Agency Regulatory Model (AERMOD) for estimation of odor, hydrogen sulfide and ammonia impacts from AFOs. Additionally, the workgroup recommends continual review of new or enhanced dispersion modeling systems, and further evaluation of AERMOD through investigation of proper model configuration and setting selection.